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ENGINEERING

WIRELESS DATA ACQUISITION AND MONITORING FOR HEALTHCARE SERVICE SYSTEMS

A thesis in the partial fulfillment of the requirement for the

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AMIR HOSHANG KIOUMARS

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This thesis is dedicated to my brother

Hashem Kioumars

For his endless love, support and encouragement

In memory of the victims of the Feb 2011

Christchurch earthquake

"Any intelligent fool can make things bigger, more complex, and more violent. It takes a touch of genius - and a lot of courage - to move in the opposite direction."

Albert Einstein (1879 - 1955)

ABSTRACT

The aging population brings challenges to healthcare systems. To cope with the high demand on health professionals and services, the feasible solution is to engage modern technologies. Wireless communication, service robots and information technology have become the active research areas for future healthcare systems. In the field of human health, collecting and analysing the real-time data is vital. New facilities and advanced tools give health service providers and their patients more choices to readily access and use health information and collect and store real-time health data. Information technology (IT) has the potential to improve the quality, safety, and efficiency of healthcare. IT allows healthcare providers to collect, store, retrieve and transfer information electronically. Together with modern communication technologies and intelligent systems, patients are able to monitor their own vital health signs from home and communicate the results to their health providers wirelessly. This will increase the ability to address a problem before a patient requires acute care. The ability to remotely monitor vital signs of a patient in real-time using a simple, low-cost and compact device with a minimum training time is highly desirable in a society with an increasing aging population.

This research outlines the design and development of a cost effective and reliable wireless sensing device for collecting real-time health vital signs such as human body temperature and heart rate. A software system is also developed to provide two-way communications with the remote sensor device in order to receive and store the collected data by the sensor device in a central database. The literature review led to the use of ATmega micro-controller, ZigBee technology for wireless communication and the development of highly adaptable, flexible and intelligent software written in Microsoft C-Sharp (C#). A unique communication data packet is also developed and implemented to overcome the micro-controller memory limitations, improving the reliability of the communication and increasing the security of data as well as saving power. The system is able to communicate with service robots and host computers via the network of XBees.

The proposed hardware device is able to collect the human heart rate and body temperature in real-time. It is light-weight, low-cost, power efficient and maintainable. It can be wrapped around the wrist and carried with the person. It transmits the data when it is needed and stays on sleep mode to save power.

The developed software system (T-HBR, stands for temperature-heart beat rate) is capable of receiving the data from the remote device and storing the data to a central database. T-HBR allows health professionals such as general practitioners (GPs), nurses and healthcare providers to be able to collect the real-time data, see the patient's history, issue a new

prescription and send it to the patient, other GPs or nurses by e-mails or text messages. The software can be a component of an individual system or can be used within a network connected to a central database. The software system supports a high level of security by using ten different types of encryption algorithms and is also able to import data from other T-HBR software and merge them into the existing database. It is component-based software with a three-layer architecture, which allows each component of the system to be replaced separately. Such a design approach reduces the cost of maintenance and enables more functionality to be added easily.

Three papers, two published and one submitted, have been the outcome of the research in this dissertation[1]:

- **Wireless Network for Health Monitoring**
  Fifth International Conference on Sensing Technology
  28th November – 1st December 2011
  Palmerston North, New Zealand
  pp. 378-385, ISBN 978-1-4577-0166-5

- **ATmega and XBee-Based Wireless Sensing**
  Fifth International Conference on Automation, Robotics and Applications
  6th – 8th December 2011
  Wellington, New Zealand
  pp. 361-365, ISBN of 978-1-4577-0328-7

- **Wireless Health Data Acquisition**
  14th International Conference on E-Health Networking
  10th – 13th October 2012
  Beijing, China
  (Submitted)

[1] *Appendix A: Publications*

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INTELECTUAL PROPERTY STATEMENT

This research was conducted in collaboration with Dr Liqiong Tang and Massey University New Zealand. Aspects of this research, particularly the designed hardware sensor, the micro-controller codes, proposed communication methodology and the developed software system are commercially sensitive. The software codes have not been provided in the publications of this research and only abstract diagrams are used to illustrate their functionalities.

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CHAPTER 1 - INTRODUCTION

Healthcare systems are facing new challenges as the population is rapidly aging and the rising healthcare spending. According to the U.S. Bureau of the Census, the population aged between 65 and 84 is expected to increase from 35 to nearly 70 million by 2025. This trend is global, so the worldwide population over age 65 is expected to increase from 357 million in 1990 to 761 million in 2025. Also, overall healthcare expenditures in the United States reached $1.8 trillion in 2004 with almost 45 million Americans uninsured. In addition, a recent study found that almost one third of U.S. adults were serving as informal caregivers to their elderly parents. It is projected that healthcare expenditures will reach almost 20% of the Gross Domestic Product (GDP) in less than 10 years, threatening the wellbeing of the entire economy[1]. All these statistics suggest that healthcare needs a major shift toward more scalable and more affordable solutions. Restructuring the healthcare systems toward proactive managing of wellness rather than illness and focusing on prevention and early detection of disease emerge as the answers to these problems.

The key to making the healthcare system affordable is to engage modern technologies. One trend is developing healthcare service robots. Such robots are becoming important assistants to healthcare professionals. The functionalities and the level of service that service robot can provide are becoming more and more powerful and intelligent. Such service robots are able to work in hospitals and old people homes. The other trend is the use of wireless wearable devices. Wearable health monitoring systems allow an individual to closely monitor changes in her or his vital signs and maintain an optimal health status. If such systems are integrated into a tele-medical system, it can even alert medical personnel when life-threatening signs occur. In addition, patients can benefit from continuous long-term monitoring as a part of a diagnostic procedure. They can also achieve optimal maintenance of a chronic condition, or can be supervised during recovery from a surgical procedure for instance. “Long-term health monitoring can capture the diurnal and circadian variations in physiological signals. These variations, for example, are a very good recovery indicator in cardiac patients after myocardial infarction”[2].

According to a study by University of Auckland, New Zealand, the age of population of the world is growing rapidly. It is predicated that by 2050, the population aged 85 and over will be three times more than it is now. This will cause several issues in the current health service system, especially workforce shortages on general practitioners and nurses in the health sector. To face

[1] National Coalition on Healthcare, from www.nchc.org/facts/cost.shtml: Retrieved June 2011

[2] Heart rate variability measurements, from qjmed.oxfordjournals.org: Retrieved June 2011

these issues, home-based healthcare devices have been identified as necessary in many developed countries to promote in-place and independent health service in order to lower the demands on health services, improve the quality of the services delivered and maintain the quality of life of the patients.

This research developed a wireless sensor device that is capable of measuring some of the vital sign of health, recording the data, interacting with remote service robot, host computer and triggering and alarming healthcare environments such as hospitals. Currently the device includes a low-cost, lightweight and small wireless sensor module as well as a software system. This sensor device is able to communicate with service robots and the host computer using a unique communication methodology that makes the communication more reliable and robust.

1.1. The research topic

The aim of this research is to develop a hardware device consisting of a temperature and a heart rate sensor, a software system that is able to wirelessly communicate with the sensor device and a communication methodology for interfacing the hardware and software. The objectives are:

- Design a hardware device that is capable of gathering some of the patient's vital signs of health such as temperature and heart rate. The device is aimed to be small, lightweight and cheap. The hardware sensor must be wearable.
- Develop a software system that is able to receive, store and process the data collected by the sensor. The software must be able to communicate with the remote device and program it wirelessly
- Create a wireless network of XBees to establish a reliable two-way communication between software and hardware

1.2. The scope of research

The scope of this research is to develop a lightweight, small, cheap and reliable wireless sensor device for smart healthcare that will open up new opportunities for continuous monitoring patients' health status at both home and hospital.

Medical service systems can extend healthcare from the traditional clinical hospital setting to retirement homes and individual families based on the following requirements:

- Integration with the existing medical practices and technologies
- Real-time and long-term monitoring
- Wearable sensors to assist chronic patients, elders and handicapped people

For enabling such a forward focused healthcare system without the prohibitive costs, it needs to have:

- A wireless sensor device for real-time monitoring the patients' health status and data collection
- An ad-hoc wireless sensor network that guarantees a reliable communication with high level of security
- A software system with a secure database that is capable of managing the health information as well as directly controlling the remote sensor devices

1.3. Organization of thesis

This dissertation contains six chapters and nine appendices. The development work of the communication, hardware and software are presented in the chapters in detail as well as including the hardware components technical data sheets, micro-controller and software programming methods, sensor outputs, hardware and software drawings and other information in the appendices. Each of the following paragraphs gives a brief description of each chapter in the dissertation.

Chapter 1 outlines the introduction and the scope of the research.

Chapter 2 deals with a background study on the importance of information technology in healthcare, vital signs of health, robots and their classifications, wireless sensor networks, ZigBee technology and real-time health monitoring.

Chapter 3 describes the communication methodology and the XBee and RF technologies and explains different types of XBee networks.

Chapter 4 focuses on the development of the hardware sensor device. This chapter explains in detail the making and prototyping of a temperature and heart rate sensor and the methodologies implemented to increase the accuracy and reliability of the sensor.

Chapter 5 covers the development of the T-HBR software. It presents the two widely used database schemas, the programming language to use to develop the software and the methodologies, design patterns and functionalities implemented in the software. This chapter also discusses the novel methodology that is introduced by this research to increase the reliability of the communication as well as saving power.

Chapter 6 describes the discussion, contribution of author, result analysis and conclusion of the research carried out and the recommendations for future improvements. The discussion outlines the success of the hardware and software developed by this research.

Appendix A includes the published conference papers carried out by this research as well as their poster and presentation slides.

Appendix B contains the micro-controller unit testing modules.

Appendix C details the T-HBR software diagrams, metrics as well as system software and micro-controller programming requirements.

Appendix D is the sample data gathered by the temperature and heart rate sensors.

Appendix E presents the assembly of each hardware component.

Appendix F contains hardware components and their costs.

Appendix G details the hardware device assemblies.

Appendix H shows some of the hardware test results.

Appendix I is the major components datasheets used in designing the hardware device. Some of the datasheets are not completely attached due to their size. It is only attached the important information of the datasheets.

CHAPTER 2 – LITERATURE REVIEW

Wireless sensor network technologies and their associated hardware have many applications in medical health systems. One of several interests is the ability to monitor important health signs from a distance. Portability, ease of deployment, scalability, real-time capability, reconfiguration and self-organization are some of the advantages of using a wireless sensor network in a healthcare system [1]. Information technology (IT) has a lot of potential to improve the quality, safety and efficiency of healthcare. The role of IT in healthcare varies and surveys indicate that more effort and investment is planned for IT in healthcare [2]. The healthcare quality of service is one of the important areas that can be improved through the investment in IT. Barriers include the cost and complexity of IT implementation, which often necessitates a significant workload and implementing cultural changes. "Certain characteristics of the healthcare market including payment policies that reward volume rather than quality and a fragmented delivery system can also pose barriers to IT adoption" [2]. In recent years, both private and public sectors have been involved in numerous efforts to promote IT's potential within the healthcare settings. Additional steps could include financial incentives (for example payment policy or loans) and expanded efforts to standardize records' formats and communication protocols to enhance interoperability.

2.1. Information technology in healthcare

IT allows healthcare providers to collect, store, retrieve and transfer information electronically. However, the IT challenges in healthcare are due to the lack of precise definitions, the volume of applications and a rapid pace of change in technology [2].

The exact functions of a system depend on the specifications of its implementation in a given setting. Both the terms and the functions can be changed over time. For example, computerized order entry can minimize handwriting or other communication errors, but they can apply only to prescription drugs or include additional orders such as x-rays or other images, consultations and transfers. Multiple definitions for Electronic Health Records (EHRs, also known as electronic medical records, automated medical records and computer-based patient records) exist depending on the constellation of functions that are included. They can be used simply as a passive tool to store the patient's information or include multiple decision support functions such as individualized patient reminders and prescribing alerts"[1].

[1] *Health Care Industry, from www.sptechnolab.com/health-care-industry: Retrieved June 2011*

There are hundreds of applications which are offered by numerous vendors. Therefore, when purchasing IT, multiple functions must be considered. In general, the various IT applications fall into three categories [2]:

- Administrative and financial systems: facilitate billing, accounting, and other administrative tasks
- Clinical systems: facilitate or provide input into the care process
- Infrastructure: supports both the administrative and clinical applications

By having service providers and their patients to access to health information, IT has the potential to improve the quality, safety, and efficiency of healthcare. However, relatively few healthcare providers have fully adopted IT and its benefits in their organization [3]. This is partly due to the complexity of IT investment which goes beyond acquiring technology to changing work processes and cultures. It must be ensured that General Practitioners (GP's), nurses and other staff will accept the new technologies before any investments are made. In addition, certain aspects of the market such as payment policies that reward quantity/volume rather than quality and the fragmentation of care delivery, do not promote IT investment. In terms of the IT potentials, policy makers need to better understand how information technology is diffusing across providers, what actions to spur further adoption are needed, and what steps might be taken [4]. Any policy to stimulate further investment must be carefully considered in case of unintended consequences such as implementation failures due to inability to make the necessary cultural changes by the organizations. Delivering a high quality healthcare requires the providers and patients to integrate information from many different sources [2]. Thus, increasing the ability of GP's, nurses, clinical technicians and others to easily access and use the valid information about their patients must be considered carefully. The ability to obtain health information by patients will allow them to better manage and monitor their health condition and to communicate with the health systems. This will improve the efficiency and quality of healthcare.

A survey on 'hospital investment priorities' that was done by the HealthCare Financial Management Association (HFMA) USA in 2004 within 460 hospitals indicates that investing in IT in healthcare is in the high priority as capital construction. This survey shows that "72% anticipate investing in Picture Archiving and Communications System (PACS: is a technology that captures and integrates diagnostic and radiological images from various devices such as x-ray and MRI, stores and disseminates them to a medical record, a clinical data repository, or other points of care), 64% in Computerized Provider Order Entry (CPOE: is typically a medication ordering and fulfilment system as well as including the lab orders, radiology studies, procedures, discharges, transfers, and referrals), and 61% in other major information technology" [2]. The same survey found that overall capital spending is expected to rise 14% annually for the next few years, compared with 1% annual increases from 1997 to 2001.

According to HFMA, until June 2004, many organizations and hospitals have announced their IT plans. For example, Kaiser Permanente, an integrated system, is investing $1.8 billion to put in place a fully operational EHR. Catholic Health West (CHW) recently announced its intention to implement various forms of health IT for all of its 41 hospitals.

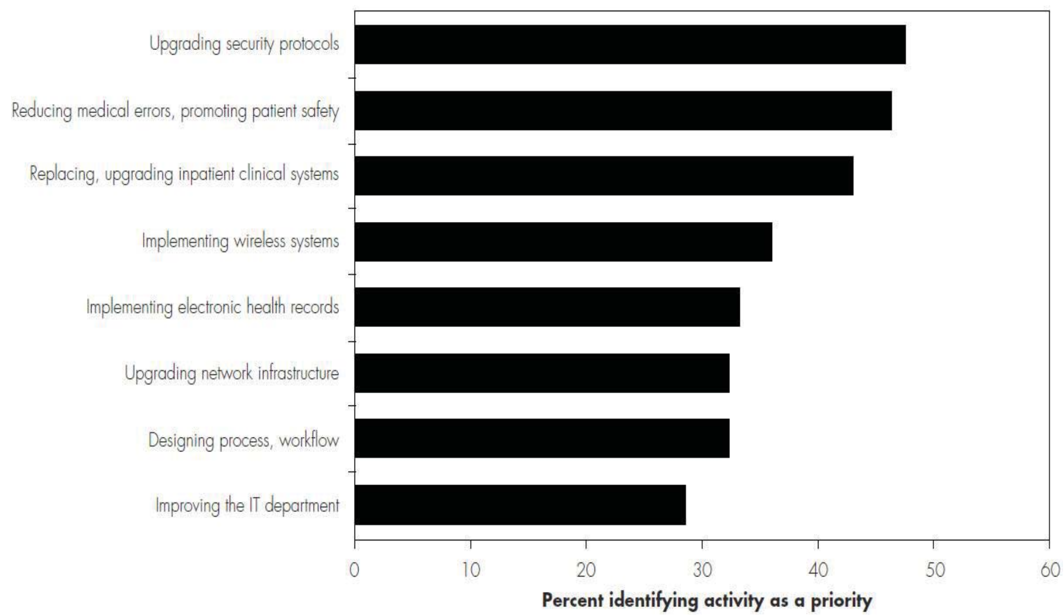

Fig 1: Hospital and healthcare security and safety as top priorities for 2004 [2]

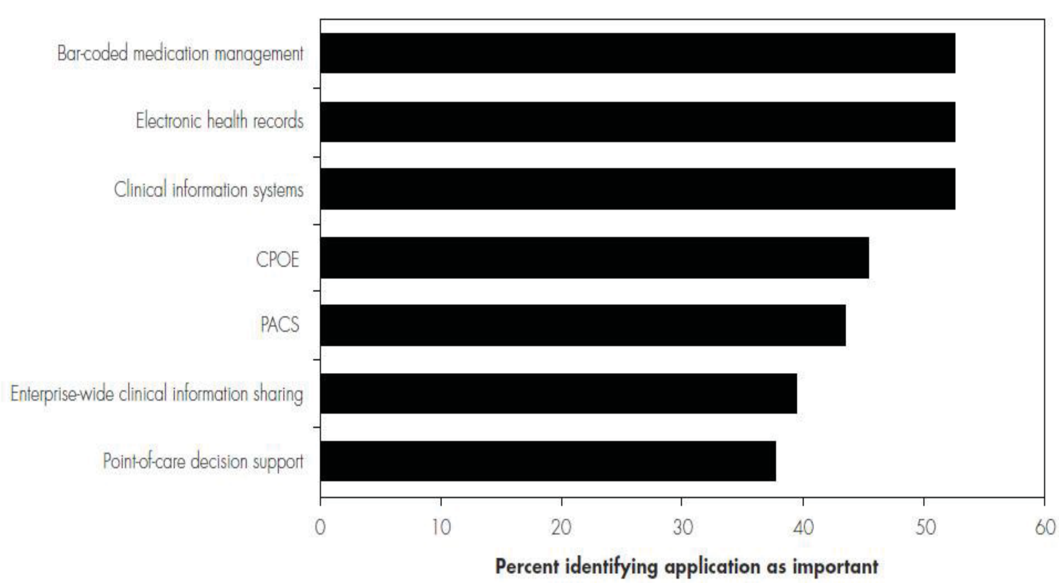

Fig 2: Hospital and healthcare clinical applications as most important for 2004–2005 [2]

2.2. Human vital health signs and their measurements

Vital signs are measures of various physiological statistics, often taken by health professionals, in order to assess the most basic body functions. These signs may be watched, measured, and monitored to check an individual's level of physical functioning. The act of taking vital signs normally entails recording body temperature, pulse (or heart rate), blood pressure, and respiratory rate, but may also include other measurements. Vital signs often vary by age [5].

2.2.1. Body temperature

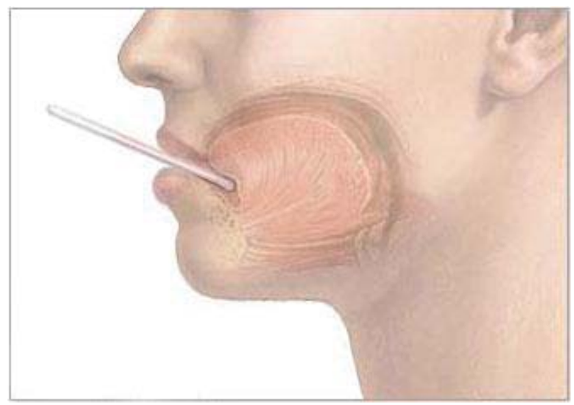

Fig 3: Oral test of body temperature

Temperature recording gives an indication of core body temperature. It is normally tightly controlled (thermoregulation) as it affects the rate of chemical reactions. Temperature can be recorded in order to establish a baseline for the individual's normal temperature for the site and measuring conditions. The main reason for checking body temperature is to solicit any signs of systemic infection or inflammation in the presence of a fever (temperature > 38.5°C) or sustained fever (temperature > 38°C), or elevated significantly above the individual's normal temperature.

A patient with a fever of 38°C does not necessarily indicate an ominous sign if his previous temperature has been higher. Body temperature is maintained through a balance of the heat produced by the body and the heat lost from the body.

There are several tools exist to measure the human body temperature which can be classified by their technologies[1]:

- Liquid-filled: it consists of a glass tube with a bulb at one end containing a liquid which expands in a uniform manner with temperature. The bulb is placed in the location where the temperature is to be measured and left long enough to be certain to reach thermal equilibrium (typically three minutes). These kinds of devices are big, heavy and hard to carry or attached to the person’s body. They are easy to break and designed to be used with in the closed environments and must be used in clinical thermometers with protection from breakage of the tube.
- Mercury: Mercury-in-glass thermometers are considered as the most accurate liquid-filled types. However, mercury is a toxic heavy metal, and mercury has only been used in clinical thermometers if protected from breakage of the tube.

[1] *Human Body Temperature, from en.wikipedia.org/wiki/Human_body_temperature: Retrieved July 2011*

- Digital thermometers: These types of devices are compact and inexpensive for measuring and displaying temperature. They display numeric values with the great precision (maximum of 0.1 degrees centigrade). Digital thermometers are big and must be placed under tongue or armpit.
- Contact: Electronic thermometers may work by contact. They are placed in the location where temperature is to be measured, and left long enough to reach equilibrium. These types of sensors are cheap, light and easy to use almost anywhere and can be easily connected to any other electronics devices.
- Remote: Other electronic thermometers work by remote sensing: an infrared sensor responds to the radiation spectrum emitted from the location. These types of sensors have the risk of patient cross-infection.
- Basal thermometer: A basal thermometer is a thermometer used to take the basal (base) body temperature. Basal body temperature is much less affected than daytime temperature by environmental factors such as exercise and food intake. This allows small changes in body temperature to be detected. They usually run between $10NZ to $15NZ.

2.2.2. Blood pressure

Fig 4: Blood pressure

"Blood pressure is the pressure exerted by circulating blood upon the walls of blood vessels" (Wikipedia, retrieved June 2011). The blood pressure is recorded as two readings; a high systolic pressure, which is the maximal contraction of the heart, and the lower diastolic or resting pressure [5]. A normal blood pressure would be 120 over 80 (systolic over diastolic). Usually the blood pressure is read from the left arm close to the heart unless there is damage to the arm. The difference between the systolic and diastolic pressure is called the "pulse pressure". The measurement of these pressures is now usually done with an electronic sphygmomanometer (Wikipedia, retrieved June 2011):

- The most common blood pressure measurement tool is a cuff that is wrapped around the upper arm. A tube attaches the cuff to a reservoir of mercury at the bottom of a vertical glass tube. Using a rubber bulb, the healthcare practitioner blows air into the cuff, making it tight around the arm. This pressure moves the mercury in the column--up with a heartbeat and down when the heart is resting between beats. While watching the level of mercury, the practitioner uses a stethoscope to listen to the pulse while the air is being released. Blood pressure measurements are shown as two numbers and measured in levels of mercury, for example: 120/80mmHg. The first number (120) is systolic pressure, measured when the pulse is first heard. The second number (80) is diastolic or resting pressure, when the pulse is no longer heard and the mercury level drops.

- Electronic measuring devices are becoming more common because mercury is now considered a hazardous substance. Electronic devices can eliminate some of the human error that can occur using a blood pressure cuff and a stethoscope.

2.2.3. Pulse

Fig 5: Pulse

The pulse is the physical expansion of the artery. Its rate is usually measured either at the wrist or the ankle and is recorded as beats per minute. The pulse commonly taken is from the radial artery at the wrist. If the pulse cannot be taken there, it can be taken at the elbow (brachial artery), at the neck against the carotid artery (carotid pulse), behind the knee (popliteal artery), or in the foot “dorsalis pedis” or “posterior tibial” arteries. The pulse rate can also be measured by listening directly to the heartbeat using a stethoscope. The heart is one of the most vital organs within the human body. It acts as a pump that circulates oxygen and nutrient carrying blood around the body in order to keep it functioning [5].

- Electrocardiography (ECG) is a transthoracic (across the thorax or chest) interpretation of the electrical activity of the heart over a period of time, as detected by electrodes attached to the outer surface of the skin and recorded by a device external to the body. ECG is normally used in hospitals or health centres and requires the system to be used by an operator and perhaps interpret the data. ECG is not good for transmitting the data wirelessly due the amount of collected data.
- Modern heart rate monitors usually comprise two elements: a chest strap transmitter and a receiver. These types of device must be wrapped around the chest which is a bit difficult for some patient suffering from a skin infection, for example. They are also slightly expensive to use.
- Infrared lights can be used to measure the heart rate. These types of devices are cheap, light and can be used almost anywhere and with any other electronics devices.

2.2.4. Respiratory rate

Respiratory rate is the number of breaths taken within a set amount of time (typically within 60 seconds). It is varies with age, but the normal reference range for an adult is 12–20 breaths per minute. The value of respiratory rate as an indicator of potential respiratory dysfunction has been investigated but findings suggest it is of limited value [5]. The aim of respiratory rate is to determine if the respiration is normal, abnormally fast (tachypnea), abnormally slow (bradypnea), or non-existent (apnea).

Respiratory measurement devices are used extensively for measuring the level of gases in the body. These devices typically measure the oxygen saturation levels and carbon dioxide levels to prevent hypoxia and brain damage in the patients. They are also useful in measuring long performance in order to monitor the expiration and inspiration in the patients. Red infrared lights can be used to measure the blood gas levels. These types of devices are cheap, light and can be used almost anywhere and with any other electronics devices.

2.3. Service robot in healthcare

Robots are a kind of device that can perform tasks on their own. They can be classified into different categories depending on their function and the market needs they are designed for. There are several major classes of robots such as industrial and service robots. The more recent classes of robots, depending on their function and use, can be divided into personal service and professional service robots.

According to the Robotic Industrial Association (RIA[1]), “an industrial robot is an automatically controlled, re-programmable, multi-purpose manipulator, programmable in three or more axes which may be either fixed in place or mobile for use in industrial automation applications” [6]. Based on the definition given by the International Federation of Robotics[2], “a service robot is a robot which operates partially or fully autonomously to provide services useful to the well-being of humans and equipment, excluding manufacturing operations”. Service robots assist humans, typically by performing a job that is dirty, dull, distant, dangerous or repetitive. They typically are autonomous and/or operated by a built-in control system[3]. ”Personal robots are a type of service robots that can educate, assist or maintain at home. These include domestic robots that may perform daily chores, assistive robots (for people with disabilities), and robots that can serve as companions” [6].

2.3.1. Demanding on service robot in healthcare

The shortage of healthcare givers around the world has motivated technological developments to address increasing healthcare demands. One solution is to use service robots. They are now being designed for interaction with patients in different environments such as hospitals. In order to achieve positive healthcare experiences, a service robot needs to be capable of detecting and responding to patient physical and emotional states. “One in eight New Zealanders are aged over 65, and this ratio is expected to rise to one in five by 2025” [8]. This is the most expensive group to care for and has the highest demand on public health services. They occupy an average of 53% of the inpatient beds in hospitals and just over a quarter of all hospital discharges. As most countries in the world are already struggling with a shortage in the medical workforce, especially nursing staff, rapidly growing demand from the ageing population is a challenge to the current health service model [9]. In the face of these issues, home-based and

[1] *Founded in 1974, RIA is the only trade group in North America organized specifically to serve the robotics industry. Member companies include leading robot manufacturers, users, system integrators, component suppliers, research groups, and consulting firms. Visit: www.robotics.org*

[2] *The International Federation of Robotics (IFR) was established in 1987 in connection with the 17th International Symposium on Robotics as a professional not-for-profit organisation by robotics organisations and associations from over 15 countries*

[3] *Reference: en.wikipedia.org/wiki/service_robot: Retrieved July 2011*

community-based healthcare services have been identified as necessary in many developed countries to promote ageing-in-place and independent living in order to lower the demands on health services and so maintain the quality of services delivered and maintain the quality of life of the older population by enabling them to be close to their families [9],[10],[11].

2.3.2. The challenges for robots

There are still many unsolved problems even fundamental issues for robotics especially for new application areas. Challenges for robots can be categorized in the following aspects [6]:

- Robot interaction with the real world: There is a need to concentrate on modelling and control efforts together with the development of good hardware to perform desired tasks
- Perception for unstructured environments: Most robots especially industrial robots have fairly primitive sensing but their perceptions are limited to a 2-Dimensional (2D) structured environment. The robot's abilities to provide 3-Dimensional (3D) environments and take actions correctly are still limited [6].
- Operational safety: Personal robots will have to operate in the vicinity of humans. Even in industry, there are many applications now where robots and humans augment each other's skills [6]. The challenge is develop both hardware and software that makes the robots safer to use.
- Human robot interaction: If robots are to work effectively in homes and other non-industrial environments, the way they are instructed to perform their jobs, and especially how they will be told to stop will be of critical importance. The people who interact with them may have little or no training in robotics, and so any interface will need to be extremely intuitive.
- Networks of robots, sensors and users**:** Most current applications see a robot operating with human user or with a collection of sensors in a very structured environment in a predetermined manner [7]. With the emergence of networks, embedded systems and the increase presence of networks in homes and hospitals and factories, robots will need to work with other robots. They need to learn from different types of sensors and interact with different human users depending on their immediate environment [6]. This is particularly important for mobile service robots whose environments are constantly changing.

2.3.3. Benefits of using service robots

Benefiting from advances in robotics and computer technology during the last few decades, robots have moved out from the domain of traditional industrial applications into human society and life. It also offers an extensive range of services [11],[10]. In healthcare, robots are able to provide automation of repetitive and time-consuming tasks in healthcare services to share the workload of staff. It mitigates the effects of increasing “patient to nurse” ratios with the aim of lowering patient mortality and make the length of stay shorter [10],[12]. It also:

- Provides enhancements for medical workers to achieve higher accuracy, efficiency and quality of services
- Provides personal care and assistance to older people as well as enhancing their quality of life physiologically and psychologically
- Serves as a companion and trainer to disabled people in their physical recovery and rehabilitation, such as post-stroke rehabilitation, and assists in therapies for patients with cognitive disabilities such as Autism Spectrum Disorder (ASD).

In addition, as robots move into health service applications in human society, provide services, assistance and even work in cooperation with humans, they must be able to engage in social interaction with human users.

2.4. Service robot decision making

Many identified robotic applications in healthcare require the robot to perform their services autonomously. Due to the complexity of the tasks, a decision-making module is essential for logic reasoning and accommodating any potential errors and recovery from mistakes [14].

2.4.1. Intelligent decision-making

In the interaction process of human and service robots, there is a need to adopt a natural interactive mode such as voice, facial expressions, vision, proximity sensing, touch etc. Fig. 6 shows the schematic diagram of a multimodal interactive platform for service robots including the main functions of the system [15]. These functions can help to achieve a simple natural Human-Robot Interaction (HRI).

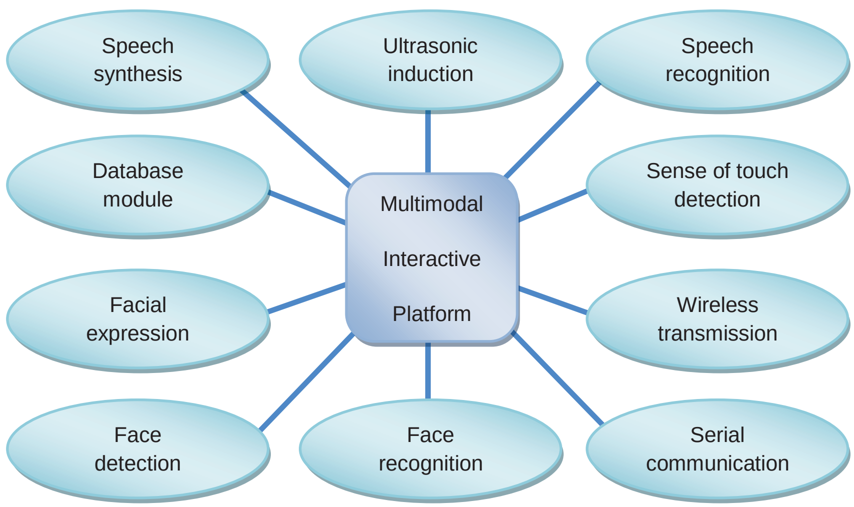

Fig 6: Schematic diagram of multimodal interactive platform of service

Intelligent decision-making of a service robot is at the core of achieving HRI. Fig. 7 illustrates the process of intelligent decision-making [15]. The decision-making system is able to cope with different types of interaction information coming from various interactive channels. Any information received, it will be decomposed to extract the attribute values and then make the correct decision. More advanced intelligent systems are even able to make decisions on behavior. These types of systems take the various input information, current psychological state and interactive tasks as the total input, then they make decisions about the robot's current interaction behaviors based on behavior decision-making algorithms, rules, action databases, and knowledge databases. Then the interaction behaviours will be exported to the compounding module for a combination of acts.

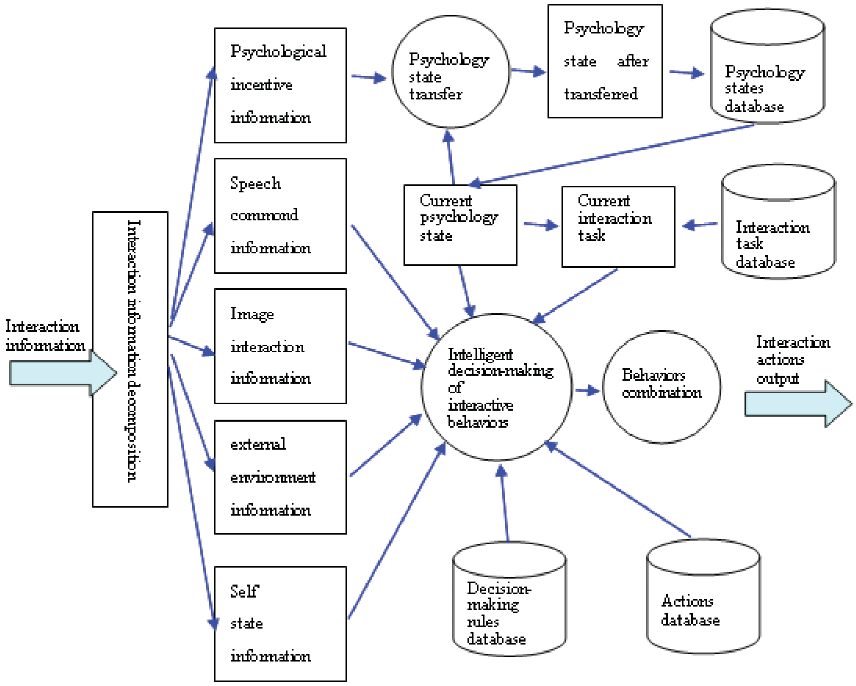

Fig 7: The process of intelligent decision-making

2.4.2. Technology roadmap for service robot

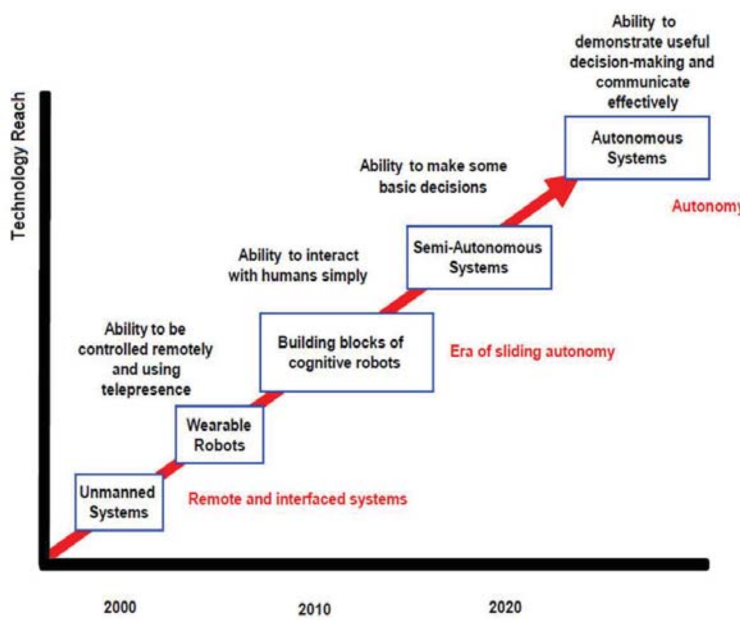

Fig 8: Service robots technology roadmap

The high expectation on service robots is driving the fast development in robotics and intelligent control. The research and survey in the development and application of robots shows that every five to ten years there is a jump in robot design in terms of functionality. Fig 8 is a predicated technology roadmap for service robots. Currently service robots are capable of interacting with humans simple functionalities, however, it is predicted that, in the near future, service robot will be able to communicate human beings effectively, make intelligent decisions and take action correctly and accurately [17].

2.5. Wireless sensor networks

Recent technological advances in sensors, low-power integrated circuits and wireless communications have enabled the design of low-cost, miniature, lightweight, and intelligent sensor nodes. These devices can be integrated into Wireless Personal or Wireless Body Area Networks (WPANs or WBANs) nodes. They are capable of sensing, processing and communicating. These networks promise to revolutionize organizations such as healthcare by allowing inexpensive, non-invasive, continuous, ambulatory health monitoring with almost real-time updates of medical records via the network [18].

2.5.1. Recent technologies

The advance in the latest technologies enables the integration and miniaturization of physical sensors, embedded micro-controllers and radio interfaces on a single chip. Wireless networking and micro-fabrication have enabled a new generation of wireless sensor networks suitable for many applications. For example, they can be used for habitat monitoring [21], machine health monitoring and guidance, traffic pattern monitoring and navigation; plant monitoring in agriculture and infrastructure monitoring [22].

One of the most exciting application domains is health monitoring [23],[24]. A number of physiological sensors that monitor vital signs, environmental and location can all be integrated into a Wearable Wireless Body/Personal Area Network (WWBAN) [25]. The WWBAN consists of inexpensive, lightweight, and miniature sensors. They allow long-term, unobtrusive and ambulatory health monitoring with instantaneous feedback to the user about the current health status and/or real-time updates of the user’s medical records. Such a system can be used in various conditions and even early detection of medical conditions. For example, intelligent heart monitors can warn users about impeding medical conditions [26] or provide information for a specialized service in the case of catastrophic events [27].

2.5.2. Advantage of wireless sensor network for healthcare

The advantages of Wireless Sensor Networks (WSNs) are numerous for smart healthcare as they provide the following important properties:

- Portability: Small devices collect data and communicate wirelessly and operate with minimal patient input. They may be carried on the body, unobtrusive helps with patient acceptance and minimizes confounding measurement effects. Since monitoring is done in the living space, it will be safer and more convenient for the patient as they do not need to travel often [32].

- Ease of deployment and scalability: WSNs devices can be deployed in potentially large quantities with dramatically less complexity and cost compared to wired networks [33]. Existing structures can be easily augmented with WSNs, whereas wired installations would be expensive and impractical. WSNs devices can be placed in the living space and can be calibrated automatically.
- Real-time and always-on: Physiological and environmental data can be monitored continuously with WSNs, allowing real-time response by healthcare workers.
- Reconfiguration and self-organization: Since there is no fixed installation, adding and removing sensors instantly reconfigures the network [34].

5.2.3. Requirements for wireless medical sensors

Wireless medical sensors should also satisfy the main following requirements:

- Wear-ability: To achieve an unobtrusive continuous health monitoring, wireless medical sensors should be lightweight and small. The size and weight of the sensors are predominantly determined by the size and weight of their power source. In addition, the battery's capacity is directly proportional to its size, which might make a long-life sensor device heavier.
- Reliable communication: This is of utmost importance for medical applications. The communication requirements for different medical sensors vary and depend on the sampling rates. One approach to improve reliability of communication is to move beyond telemetry by performing on-sensor signal processing. For example, instead of transferring raw data from a sensor, it is possible to perform some feature extraction first and transfer only the required information [35]. This also minimizes the need for heavy demands for a communication channel, saves on total energy expenditures and consequently increases battery life. A careful trade-off between communication and computation is crucial for optimal system design.
- Security: WSNs overall system security is another crucial aspect. At the lowest level, wireless medical sensors must meet privacy requirements mandated by the law for all medical devices and must guarantee data integrity. However, key establishment, authentication and data integrity are challenging tasks in resource constrained medical sensors. A relatively small number of nodes in a typical WWBAN and short communication ranges make these tasks achievable.
- Interoperability: Wireless medical sensors should allow users to easily assemble them depending on the user's state of health. Standards that specify interoperability of wireless medical sensors will promote vendor competition and eventually result in more affordable systems [35].

2.6. Wireless communication technologies

"Since the development of wireless communication technology has been extremely vigorous, the mutual interference issue in the ISM band has been explored quite intensively in recent years." [36] Some of the important existing technologies which play important roles in today's communication area are Bluetooth, WiFi (as Wireless Local Area Network or WLAN), ZigBee (as Wireless Personal Area Network or WPAN) and WiMAX (as Wireless Metropolitan Area Network or WMAN). Fig. 9 graphically illustrates the types of wireless communication technologies commonly used [36]:

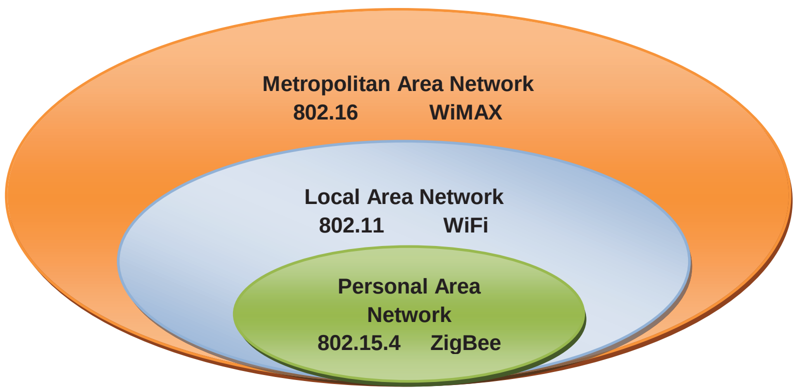

Fig 9: Types of wireless communication technologies

Most of these wireless technologies cannot be islands in themselves, but will offer some inter-connectivity between each other. This will help in creating a perfectly connected environment. For example, in a simple weather station network, the information is gathered, communicated by tiny sensors based on ZigBee and passed over radio waves from one to another. At the end of the line, the data is picked up by hotspots created by WiMAX or WiFi.

2.6.1. WiFi

"Demand for wireless network hardware has experienced phenomenal growth during the past several years, evolving quickly from novelty into necessity" [37]. WIRELESS FIDELITY (WiFi) technology is the most common technology which can be found in notebook computers and Internet access devices such as routers. The growth of WiFi technology is helping to extend the technology from PC's into electronics applications like Internet telephony, music streaming, gaming and in-home video transmission. These usages as well as

Fig 10: WiFi logo

the growing number of conventional WLAN users are increasingly straining the existing Wi-Fi networks. The industry has come to an agreement on the components that will make up 802.11n. WiFi802.11n is a WLAN standard that promises higher data rates and increased reliability. WiFi802.11n is a data transmission technology that is designed to provide “location-independent” network access between devices by using radio waves. Wi-Fi is meant to be used generally when referring to any type of 802.11 networks such as 802.11b, 802.11a, 802.11g etc. 802.11b networks can move data at up to 11 megabits per second (Mbps), 802.11a with maximum speed of 54Mbps and throughput of around 25Mbps. 802.11g wireless devices were quickly embraced by consumers and businesses seeking higher bandwidth [38]. The next WiFi speed standard, 802.11n, will likely offer a bandwidth of around 108Mbps and because it will be industry standard, 802.11n compliant devices will be interoperable [39].

2.6.1.1. Characteristics of 802.11n

The emerging 802.11n specification differs from its predecessors. It provides for a variety of optional modes and configurations that dictate different maximum data rates. This enables it to provide baseline performance parameters for all 802.11n devices, while allowing manufacturers to enhance capabilities to accommodate different applications. With every possible option enabled, 802.11n can offer raw data rates up to 600 Mbps. Most available WLAN hardware are expected to support raw data rates up to 300Mbps [38]. In comparison, every 802.11b compliant product support data rates up to 11 Mbps, and all 802.11a and 802.11g hardware support data rates up to 54 Mbps. Some of the characteristics of 802.11n standard are:

- Better Orthogonal Frequency-Division Multiplexing (OFDM): support an OFDM implementation that improves upon the one employed in the 802.11a/b/g standards, using a higher maximum code rate and slightly wider bandwidth. This change improves the highest attainable raw data rate from 54 to 64Mbps in the existing standards [39].
- Multiple Input and Multiple Output (MIMO): MIMO improves performance. It exploits a radio-wave phenomenon called multipath (transmitted information bounces off walls, doors, and other objects, reaching the receiving antenna multiple times via different routes and at slightly different times). MIMO controls multipath with a technique known as space division multiplexing. The transmitting WLAN device actually splits a data stream into multiple parts known as “spatial streams”, and transmits each spatial stream through separate antennas. The current 802.11n draft provides for up to four spatial streams, even though compliant hardware is not required to support that many [39]. The 802.11n specification includes a MIMO power-save mode. It mitigates power consumption by using multiple paths only when communication would benefit from the additional performance.

- Improved throughput and higher data rates: 802.11n draft effectively doubles data rates by doubling the width of a WLAN communications channel from 20MHz to 40MHz.

2.6.2.2. Applications of 802.11n

802.11n has greater bandwidth, better range and reliability. Therefore it is advantageous in a variety of network configurations. Some of the current and emerging applications that are driving the need for 802.11n are:

- Voice over IP (VoIP): It enables consumers to save money on long distance phone calls by using the Internet instead of traditional phone service. It does not demand high bandwidth, although it does require a reliable network connection to be usable. Both 802.11b and 802.11g consume less power than 802.11n in MIMO modes, but single-stream 802.11n is more prevalent in VoIP phones [37].
- Streaming video and music: These types of streams require a highly reliable connection. Millions of consumers are building libraries of digital music on their personal computers by ripping their Compact Disk (CD) collections and buying digital recordings over the Internet.
- Gaming: It is an application that increasingly is making use of home WLANs. It enables users to connect wirelessly to the Internet from their computers and portable gaming devices.
- Network attached storage: A growing application that demands almost all the 802.11n characteristics such as high data rates as well as range and reliability is Network-Attached Storage (NAS). NAS has become popular in the enterprise as an inexpensive, easy-to-install alternative for data backup [37]. Another important application of NAS is video storage centres. It demands a reliable and high-bandwidth connection to stream pre-recorded TV shows, music videos and full-length feature films. Fig. 11 shows the required time needed by 802.11 technologies for transferring 30 minutes video [37].

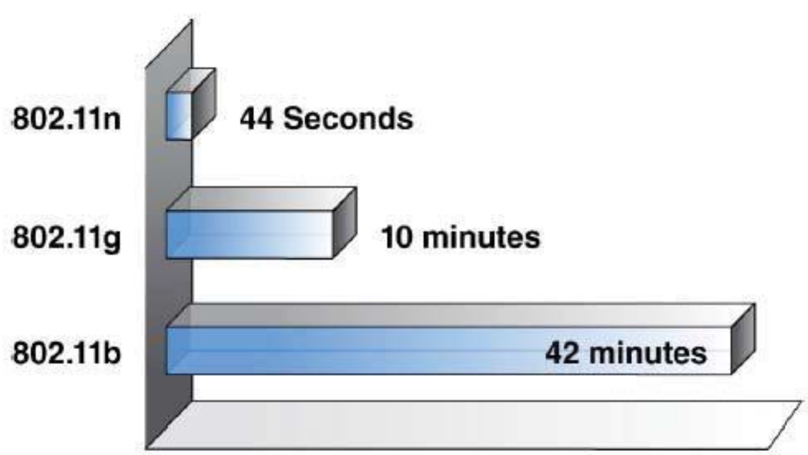

Fig 11: Time to transfer 30 minutes video

2.6.2. WiMAX

Worldwide Interoperability for Microwave Access (WiMAX for short) is a trademark for a family of telecommunications protocols. It provides both fixed and mobile Internet access. The IEEE approved the 802.16 standards in June 2004 [37]. This technology supports a high bandwidth (70Mbps) and a high range of up to 48 kilometres. WiMAX can be used for wireless networking like WiFi. It allows higher data rates over longer distances. It also provides efficient use of bandwidth, and avoids interference (almost to a minimum). “WiMAX can be termed partially a successor to the Wi-Fi protocol” [37]. WiMAX makes Internet access possible from almost anywhere. Providers can offer a broadband connection that a person can take with them when they travel. The IEEE 802.16 standard can accommodate Time Division Multiplexing (TDM) or Frequency Division Duplexing (FDD) deployments. It also allows for both full and half-duplex terminals. WiMAX uses microwave radio technology to connect computers to the Internet. WiMAX works very much like cell phone technology. It requires a proximity to a base station to establish a data link to the Internet. Users within 3 to 5 miles away from the base station will be able to establish a link using Non-Line-Of-Sight (NLOS) technology with data rates as high as 75Mbps. At distance of about 30 miles away from the base station, with an antenna mounted and using Line-Of-Sight (LOS) technology, it will be possible to have a connection with data rates of approximately 280Mbps [37].

Fig 12: WiMAX logo

2.6.2.1. Characteristics of WiMAX

Technical aspects of 802.16a that are instrumental in powering robust performance include the following characteristics[1]:

- Power varies with bandwidth. Profiles from 100 Mw up to 2W
- Spectrum: Initially 3.5GHz licensed and 5.8GHz unlicensed bands
- Radio interface: OFDM using 256 tones
- Security: via station authentication and encryption
- Data rates: variable with channel bandwidth 3.5MHz in 3.5GHz band, 20MHz in 5.8GHz
- Actual realizable data rates: approximately 2B/Hz
- Maximum range: approximately 2Km for indoor NLOS cellular service at 3.5GHz

[1] *These features are extracted from WiMAX user manual with some modifications*

2.6.2.2. Applications of WiMAX

It can serve the business, residential and mobile segments. The bandwidth and range of WiMAX make it suitable for the following potential applications:

- Residential users
  - Basic voice services, low-cost domestic and international calls
  - Basic (dialup speed) to advanced (over 1Mbps) data connections
  - Bundled voice and data services
- Business users
  - Basic data connectivity for small businesses
  - Advanced data services to medium and large businesses
  - Feature-rich, low-cost voice services such as VoIP
- Mobile users (mobile WiMAX only)
  - Data connectivity for mobile workforce
  - Data connectivity for international visitors

2.6.3. ZigBee

ZigBee is one of the most recent technologies that make Wireless Personal Area Networks (WPAN) possible. "ZigBee is the name of a specification for a suite of high level communication protocols using small, low-power digital radios based on the IEEE 802.15.4 standard" [37]. This technology is intended to be simpler and cheaper than other WPANs such as Bluetooth and intended for use in embedded applications requiring low-data rates and low-power consumption. The WPAN's that use ZigBee technology have several layers. They are designed to enable intrapersonal communication within the network, connection to a network of higher level and ultimately an uplink to the Web.

Fig 13: ZigBee logo

2.6.3.1. Characteristics of ZigBee

ZigBee is going to become a global control/sensor network standard. It has been designed to provide the following features[1]:

- Low power consumption. Battery life ranging from months to years
- Maximum data rates. 250Kbps at 2.4GHz, 40Kbps at 915MHz, and 20Kbps at 868MHz.

[1] These features are extracted from ZigBee user manual with some modifications

- High throughput and low latency for low duty-cycle applications
- Addressing space of up to 64 bit IEEE address devices. 65,535 networks
- Operation range from 70 to 100 meters
- Low device, installation and maintenance cost. ZigBee devices allow batteries to last several years using primary cells (low-cost) without any chargers (low-cost and easy installation). ZigBee's simplicity allows for inherent configuration and redundancy of network devices provides low maintenance
- High density of nodes per network. ZigBee's use of the IEEE 802.15.4 PHY and MAC allows networks to handle any number of devices. This attribute is critical for massive sensor arrays and control networks
- Fully reliable 'hand-shake' data transfer protocol
- Supports different network topologies such as star, peer-to-peer and mesh

2.6.3.2. Applications of ZigBee

The ZigBee Alliance targets applications across consumer, commercial, industrial and government markets worldwide. A recent analyst report issued by West Technology Research Solutions estimates that by the year 2008, annual shipments for ZigBee chipsets into the home automation segment alone will exceed 339 million units, and will show up in light switches, fire and smoke detectors, thermostats, appliances in the kitchen, video and audio remote controls, landscaping and security systems.

2.7. Comparison between ZigBee and Bluetooth

According to their datasheet, the bandwidth of Bluetooth is 1Mbps while ZigBee is one fourth of this value. The strength of Bluetooth lies in its ability to allow interoperability and replacement of cables [38]. The diverse application areas of all the different wireless technologies are most important in any meaningful comparison. Bluetooth is meant for use in wireless USB's and handsets, whereas ZigBee is meant to be used by the sensors, remote controls devices and other battery operated products. In general, it may be said that they are neither complementary standards nor competitors. They are essential standards for different targeted applications [37]. The Bluetooth targets interfaces between PDA and other device (mobile phone/printer etc.) and cordless audio applications. “Bluetooth has addressed a voice application by embodying a fast frequency hopping system with a master slave protocol” [37]. ZigBee has addressed sensors, controls, and other short message applications by embodying a direct sequence system with a star or peer-to-peer protocols. Table 1 shows the comparison between ZigBee 802.15.4 and Bluetooth technologies.

	802.15.4 transceiver	Bluetooth transceiver
Current per comms session at -5dBm	14mA	45mA
Length of activity per 8ms period	1772µS	N/A
Active duty cycle	1:4.5	N/A
Average current consumption (constant use)	4mA	45mA
Average current consumption when in standby/idle/sniff mode	351µA	15µA
Power down current	20µA	N/A

Table 1: ZigBee and Bluetooth comparison[1]

[1] Reference: www.eetimes.com

2.8. Comparison of WiFi, ZigBee and WiMAX technologies

Each technology seems to have a different "gauge". The main points of comparison of the three technologies that we are interested in are listed in Table 2. By reviewing the existing technologies, it is appears that 802.11n is viewed as the most likely contender for the home network backbone. ZigBee, on the other hand, is likely to make best use of its low-power and high-speed operation in short-range equipment interconnects such as personal computers and portable equipment. ZigBee networks are primarily intended for low duty cycle sensor networks (less than 1%). 802.11n is viewed as being superior in maintaining compatibility with existing wireless LAN, while ZigBee is more likely to achieve lower levels of power consumption. WiMAX enables mobile broadband at an affordable price. "WiMAX is not expected to completely eliminate the WiFi technology in the near future, but will be a complement to WiFi as its primary backhaul service of choice" [37]. WiMAX promises to help corporations expand business, drive down costs, increase overall profitability, increase the quality of service, and increase the number of users that connect to the Internet.

	WiFi - 802.11n	ZigBee	WiMAX
Application	Wireless LAN/Internet	Sensor/Networks	Metro Area Broadband/ Internet Connectivity
Typical Range	100 m	70 – 100 m	50 km
Frequency Range	2.4 GHz	2.4 GHz	2 – 11 GHz
Data Rate	108 - 600 Mbps	250 Kbps	75 Mbps
Modulation	DSSS	DSSS	QAM
Network	IP & P2P	Mesh	IP
Network Topology	Infrastructure/Ad-hoc	Ad-hoc	Infrastructure
Access Protocol	CSMA/CA	CSMA/CA	Request/Grant
Key Attributes	Wider Bandwidth/ Flexibility	Cost/Power	Throughput/ Coverage

Table 2: WiFi, ZigBee and WiMAX technologies

2.9. ZigBee benefits

ZigBee provide a standardized base set of solutions for sensor and control systems. To allow vendors to supply the lowest possible cost devices the IEEE standard defines two types of devices [40]:

- Full Function Devices (FFDs)
- Reduced Function Devices (RFDs).

An IEEE 802.15.4/ZigBee network requires at least one FFD as a network coordinator. The endpoint devices (receivers) can be RFD. They are able to reduce some of the functionalities that do not require in order reducing the overall system cost. The ZigBee has evolved standardized sets of solutions, called ‘layers' [37]. They consist of network and application support, physical and media access control layers. These layers facilitate low-cost, easy implementation, reliable data transfer, short-range operations, very low power consumption and adequate security features, making ZigBee very popular from the other wireless protocols.

2.9.1. ZigBee data reliability, rate, latency and security

The underlying 802.15.4 standard provides strong reliability through several mechanisms at multiple layers. It uses 27 channels in three separate frequency bands [36]. IEEE 802.15.4 provides three frequency bands for communications. ZigBee profile developers can optimize the system performance by having global utility, propagation, path loss and data rate differences [45].

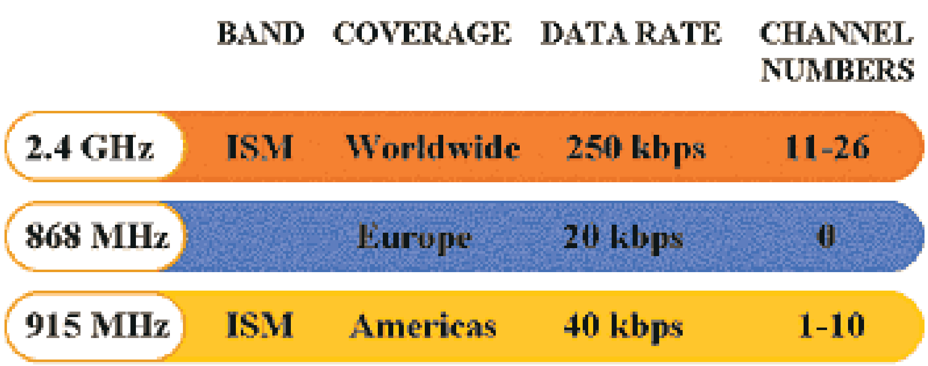

Fig 14: ZigBee frequency channels

- The 2.4GHz band is used worldwide and has 16 channels and a maximum over-the-air data rate of 250Kbps.
- The 902–928 MHz band has 10 channels and a burst rate of 40Kbps.
- 868–870 MHz band provides 20Kbps burst rate.

On a specific channel, the 802.15.4 radio relies on a number of mechanisms to ensure reliable data transmission. “First, the physical layer uses Binary Phase Shift Keying (BPSK) in the

868/915MHz bands and Offset Quadrature Phase Shift Keying (O-QPSK) at 2.4GHz. The information is coded onto the carrier with Direct Sequence Spread Spectrum (DSSS), an inherently robust method of improving multipath performance and receiver sensitivity through signal processing gain. The size of the data payload ranges from 0 to 104 bytes, which is enough to meet most sensor needs. Fig. 15 shows the construction of the data frame, also called a data packet [45]:

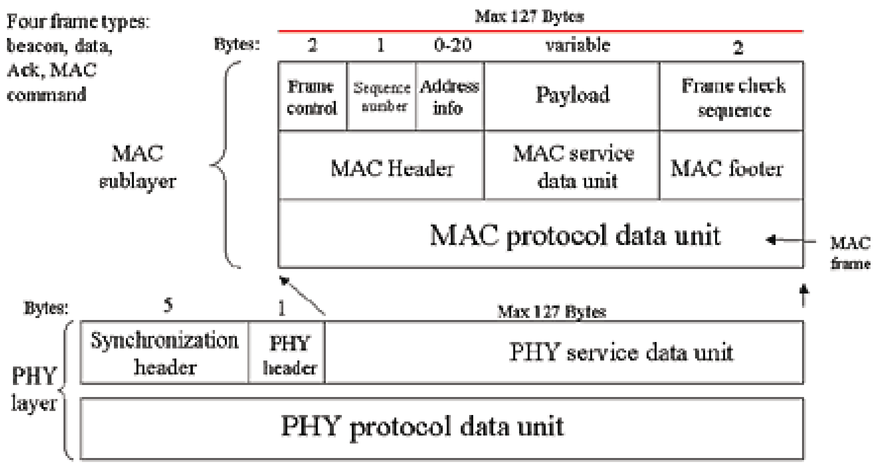

Fig 15: Frame types

The data packet is one of four packet structures provided in 802.15.4. In the MAC protocol data unit, the data payload is appended with source and destination addresses, a sequence number (allows the receiver to recognize that all packets transmitted have been received), frame control bytes (specify the network environment and other important parameters), and finally a frame check sequence (lets the receiver verify that the packet was received uncorrupted).

After receiving a data packet, the receiver performs a 16-bit Cyclic Redundancy Check (CRC) to verify that the packet is not corrupted during transmission. In case of a good CRC, the receiver can automatically transmit an acknowledgement packet to the transmitter indicating acceptance of the packet. In case of a bad CRC, the packet is dropped and no acknowledgement is transmitted. The transmitter can be programed to transmit a packet a specified number of times to ensure successful delivery. If the path between the transmitter and receiver has become less reliable or a network failure has occurred, ZigBee provides the network with self-healing capabilities if alternate paths are physically available.

Sensor systems require a broad range of data-latency. “If sensor data are needed within tens of milli-seconds, the requirement places different demands on the type and extent of the intervening network” [45]. For many sensor applications, data latency is less critical than battery life or data reliability. For simple star networks (many clients, one network coordinator), ZigBee can provide latencies as low as approximately 16ms in a beacon-centric network by using guaranteed time slots to prevent interference from other sensors.

It’s important to provide the sensor network with adequate security to prevent the data from being stolen. IEEE 802.15.4 provides authentication, encryption, and integrity services for wireless systems as required. These include a 32-bit to128-bit Advanced Encryption Standard (AES) with authentication. This security suite lets the developer pick and choose the security necessary for the application, providing a manageable trade-off against data volume, battery life, and system processing power requirements. The IEEE 802.15.4 standard does not provide a mechanism for moving security keys around a network. "The ZigBee security toolbox consists of key management features that let safely manage a network remotely" [45]. The battery life can be optimized by not implementing the security features for those systems where data security is not critical (for example a set of sensors monitoring microclimates in a forest).

2.9.2. ZigBee size, cost and battery life

With the use of current technologies and radio progress, transceiver systems can shrink in physical size. In the case of ZigBee, the radio transceiver has become a single piece of silicon, with a few passive components and a relatively non-critical board design [45]. Micro-controllers that have native ability to interface with sensors (e.g., built-in digital I/O and A/D converters) have eclipsed rapid reduction in radio size. The 8-bit Micro-Controller Unit (MCU) that hosts the application may include dozens of kilobytes of flash memory and various hardware-based timer functions, along with the ability to interface directly to the radio transceiver IC. The MCU requires only a few external passive components to be fully functional. With the minimal overhead added by a ZigBee transceiver, the MCU can often continue to host the application along with the ZigBee protocol. Therefore, the size of a ZigBee module (excluding sensors or batteries) is generally smaller than the batteries themselves. There is sufficient flexibility in both ZigBee and 802.15.4 standards to provide an optimized cost with respect to system performance. The network configuration also plays an important role in power-saving. Most networks are expected to be stars or cluster trees rather than true meshes as shown in Fig. 16, allowing the individual client devices to conserve battery energy.

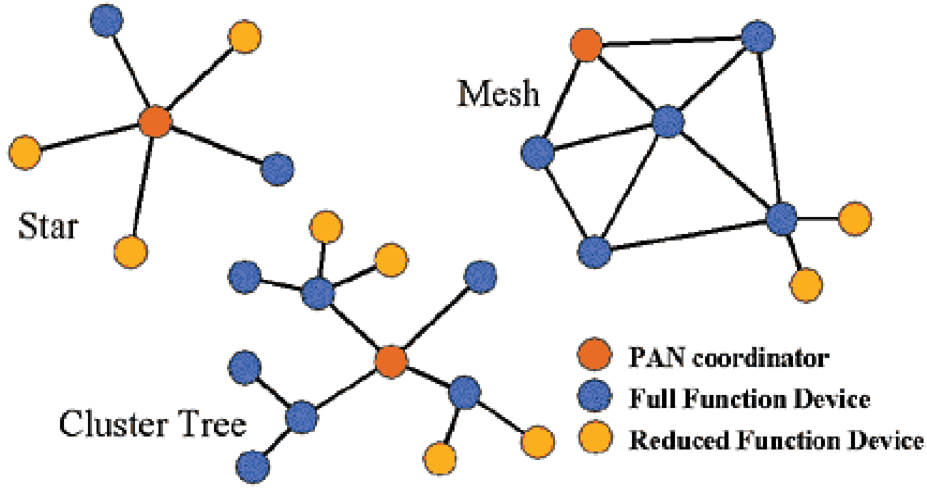

Fig 16: ZigBee star, mesh and tree networks

Star networks are the most common structure with broad utility. For larger physical environments, the cluster tree is a good way to aggregate multiple basic star networks into one larger network. Some applications make the best use of the mesh structure which provides alternate route flexibility and the capability for the network to heal itself when intermediate nodes are removed or RF paths are changed.

2.9.3. ZigBee transmission range

As a short-range wireless standard, 802.15.4 does not try to compete with high-powered transmitters. It relies on ultra-long battery life and low transmitter power. The standard specifies transmitter output power at a nominal -3dBm (0.5mW). At –3dBm output, depending on the environment, antenna, and operating frequency band, a single-hop range vary from 10 to more than 100 meters. ZigBee allows multi-hop and flexible routing, providing communication ranges that can exceed the basic single-hop. Depending on the data latency requirements, it can practically create networks that use dozens of hops with cumulative ranges over kilometres [45].

2.10. ZigBee in healthcare

The ZigBee Alliance's focus on the healthcare space has resulted in the development of the ZigBee Healthcare public application profile. "ZigBee healthcare fully supports ISO/IEEE 11073 for point-of-care medical device communication and provides support for additional devices and all device specializations. Device specializations for a number of medical devices already exist including the pulse oximeter, blood pressure monitor, pulse monitor, weight scale and glucose meter" (digi.com official website, retrieved 2011).

The shift from reactive to proactive healthcare and wellness has increased vigilance and service applications in targeted fitness and chronic disease management. Additionally, increases in adoption of connectivity and communication technology, enabling to remotely monitor health and wellness extends the services on a much wider scale. The missing piece of this puzzle is a low-power wireless connectivity. "The low-power wireless component preserves mobility while it ensures that sensing and monitoring devices preserve our independent lifestyle" [43],[44]. The ZigBee healthcare public application is specifically designed from the start with the aim of targeting these needs. ZigBee healthcare networks and applications can create a scalable network of low-power wireless nodes that are designed to sense and monitor the health and well-being of individuals. Their capabilities can make such applications possible. This unique combination of ZigBee healthcare capabilities eliminates barriers and allows the organizations to embrace this critical piece in reducing healthcare costs. It also creates a new class of tools that deliver vital lifesaving and life affirming benefits that can serve humanity [42]. Fig. 17 shows a sample application of ZigBee at home:

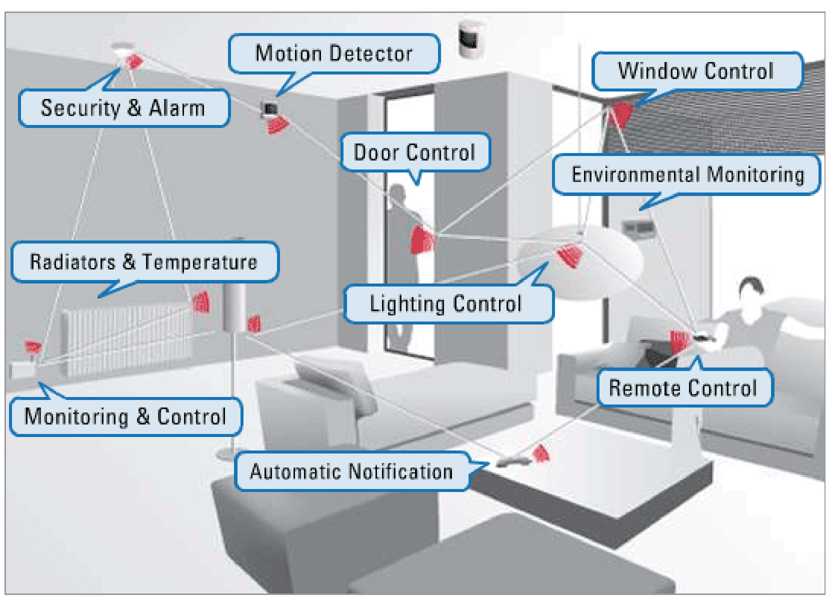

Fig 17: ZigBee sample application[1]

[1] Reference: www.focus.ti.com

2.11. Real-time health monitoring using ZigBee

Wireless sensor networks are based on a large quantity of wireless sensors using ZigBee technology. To know the physical states of a patient, the physical parameters need to be monitored real-time [44],[42]. The traditional medical instruments have a large size, often connected by wire and the patient is required to be quiet during the measurement. In most hospitals, the medical instruments need to be read by a specialist. Then the physical parameters need to be recorded daily. The real-time monitoring is expensive for most patients. For this reason, the worsening of patient health cannot be found in time. Therefore the patient can't be helped in time. Considering the fact that the patient's movement is limited within the hospital, ZigBee and wireless sensor networks can acquire the physical parameters of the patient. With wireless sensor networks, the patient only needs to carry smart wireless sensors. The real-time physical data then can be acquired and monitored by the sensor [42]. The patient physical parameters can be collected by the sensor and transmitted to a remote computer through a ZigBee network. Depending on the distance from the PC, the data can be routed through several XBee modules to reach the remote coordinator. The data can provide an auxiliary means for a doctor to diagnose the patient. Fig. 18 shows the conceptual view of a remote monitoring system:

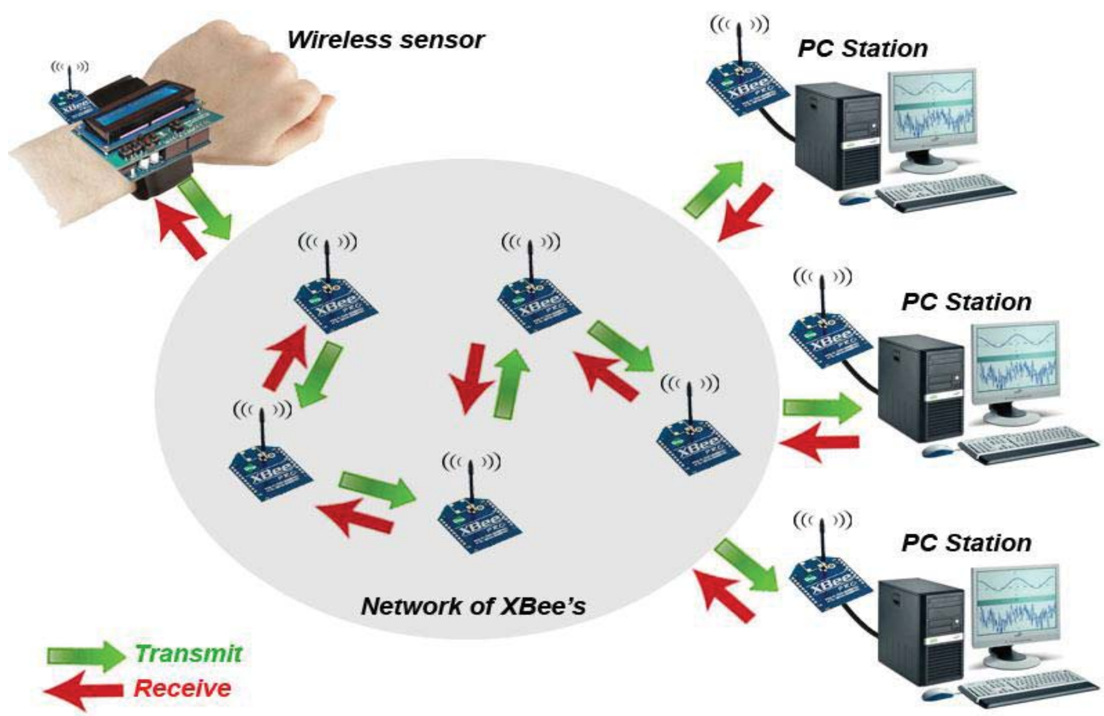

Fig 18: Conceptual view of a remote monitoring system

CHAPTER 3 – COMMUNICATION

With simple instructions, patients can operate a variety of monitoring devices such as measuring the heart rate, body temperature, glucose meters and blood pressure. Healthcare professionals are able to securely access the data being collected, making informed decisions based on the readings received from the patient. XBee networking solutions make it easy for doctors in many locations to share and compare patient information and collaborate with other specialists. Self-forming mesh networks (require no IT expertise from the patient), data security (through a combination of encryption and authentication), reliability (automatic retries and acknowledgements ensure delivery of critical data) and portability (equipment is mobile, allowing for deployment between different patients) are some of the key benefits that are offered by these kinds of networks.

3.1. Wireless communication

Wireless technology has become more popular because of its low cost, ease-of-use and cheaper than the wired alternative. This technology allows for faster and more convenient access to the world. The direct interfacing of analogue sensors and digital input/outputs (IO) makes XBee widely acceptable in the variety of areas such as wireless applications. “From a simple domestic application of temperature control to the more complex mesh sensor networks that analyse volcano, XBee devices are gradually becoming an industry standard in wireless communication” (XBee manual, retrieved 2011).

There are several features of wireless sensor devices such as[1]:

- Mobility. Wireless devices can be connected without unsightly cables. Furthermore, these devices can be much more mobilized within a certain area. For example by using the XBee, the distance can be as far as 1.6km.
- Simplicity. It is much easier and faster to setup the devices to communicate without cables. For example, if a commuting device needs to be relocated, wireless makes it a simple matter. Besides, there would be no additional cost caused by rewiring or excessive downtime and/or etc. Never the less, there would be no disruption to the remainder of the system when additional devices need to be added in or some devices need to be removed from the system.
- Flexibility. Wireless devices can be used communication where cables are not suitable, like communicating between two buildings with a lot of obstacles in between.

[1] *Reference: www.digi.com*

- Cost-saving. The cost of running and maintaining a radio based communications solution is minimal compared to the wired ones.
- Supports for multiple network topologies, such as point-to-point, point-to-multiple and mesh networks (XBee manual, retrieved 2011)
- Low duty cycle, long battery life and low latency
- Direct sequence spread spectrum
- Supports up to 65,000 nodes per network
- Uses 128-bit Advanced Encryption Standard (AES[1]) algorithm for communication

“The XBee/XBee-PRO ZNet 2.5 OEM (formerly known as Series-2 and Series-2 PRO) RF modules were engineered to operate within the ZigBee protocol and support the unique needs of low-cost, low-power wireless sensor networks” (XBee manual, retrieved 2011). These modules require minimal power and provide reliable delivery of data between devices. The modules operate within the ISM 2.4 GHz frequency bandwidth and are compatible with XBee RS-232, analogue and digital I/O, sensor and USB adapters.

Communication with XBee modules can be done either via XBee shield on an Arduino micro-controller or via a USB dongle which is connected to a computer directly. The XBee module interfaces to a host device through a logic-level asynchronous serial port. ZigBee defines three different device types: coordinator, router and end device.

- Coordinator: Allows routers, end devices to join the Personal Area Network (PAN), transmit and receive RF data transmission, and route the data through the network.
- Router: Transmits and receives RF data transmission, and routes data packet through the network
- End Device: Cannot assist in routing the data transmission but transmits or receives RF data transmission and is intended to be battery powered devices

3.2. XBee explorer

The XBee’s firmware needs to be setup before use. By default, they have a pre-programmed PAN ID[2] (Personal Area Network Identification). The XBee modules cannot connect to the computer directly and they need some sort of adapter. The XBee explorer or XBee dongle are used to connect the module to the PC and program its firmware.

---

[1] *AES is based on a design principle known as a substitution permutation network. It is fast in both software and hardware. AES has a fixed block size of 128 bits and a key size of 128, 192, or 256 bits. Reference: Wikipedia*

[2] *PAN ID prevents the radios from conflicting with other projects. Most importantly, it prevents other projects from accidentally interfering with each other. XBee networks should select one or more unique PAN IDs for themselves, and set all their radios to use those PAN IDs by default*

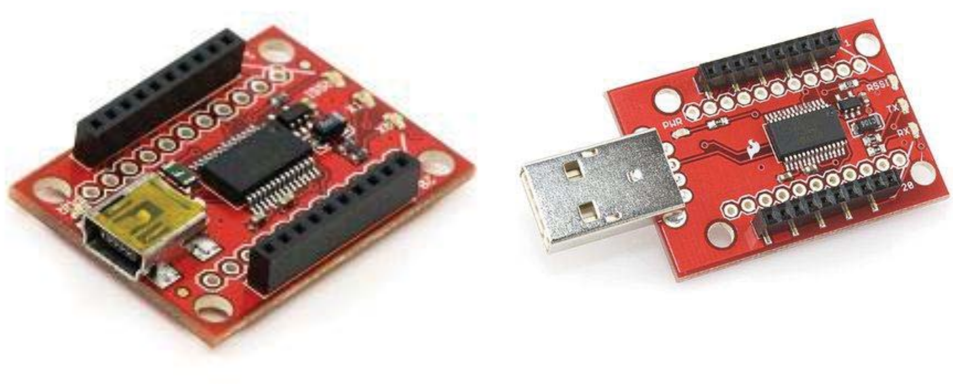

Fig 19: Mini-USB XBee explorer board (left) - USB XBee dongle (right)

3.3. X-CTU software

X-CTU[1] is a Windows-based application provided by Digi.com. This program is designed to interact with the firmware files found on Digi's RF products such as XBee by providing a simple-to-use graphical user interface. Its main functionalities are as follows:

- PC Settings: allows a user to select the desired COM port and configure that port to fit the radios settings.
- Range Test: performs a range test between two radios.
- Terminal: enables access to the computers COM port with a terminal emulation program. It also allows the ability to access the radio's firmware using AT commands.[2]
- Modem Configuration: allows programming the radio's firmware settings via a graphical user interface.

X-CTU also enables[3]:

- Integrating terminal window
- Easy to use loopback range test
- Display of Receive Signal Strength Indicator (RSSI)
- Display both ASCII and hexadecimal characters in terminal window.
- Compose test packets in either ASCII or hexadecimal for transmitting through the terminal interface
- Automatically detect module type
- Restore factory default parameters

[1] X-CTU stands for XBee-configuration and test utility

[2] Appendix I: XBee module specification

[3] These information are extracted directly from XBee manual

- Display help about each of the radio parameters
- Program radio profiles in a production environment using command line interface

Fig. 20 shows the X-CTU startup window. It lists all the devices connected to any serial port on the host PC:

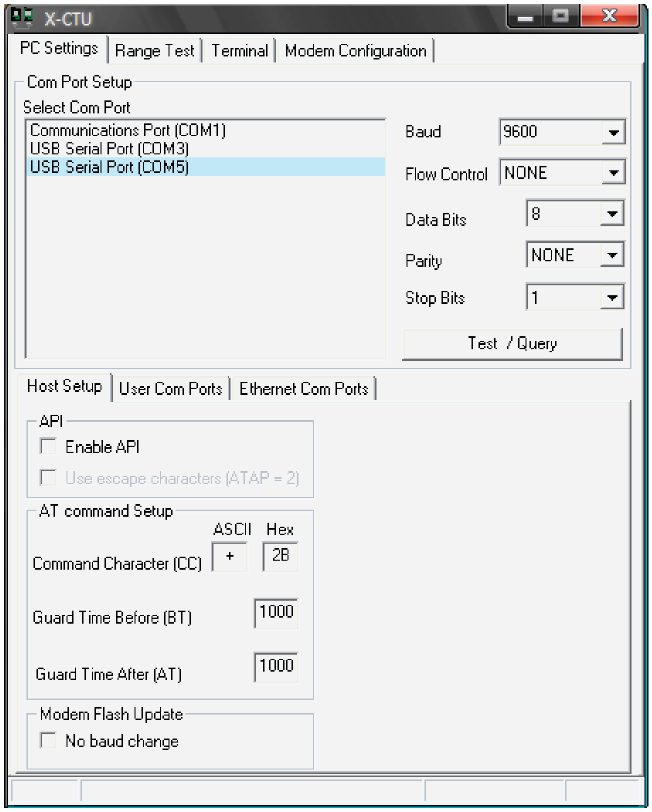

Fig 20: Running XCTU and connect to the XBee

Test/query button queries the XBee information which is connected to the PC. If the test/query of a selected device is successful, the XCTU will display a message indicating the status of communication, modem type and firmware version of the module:

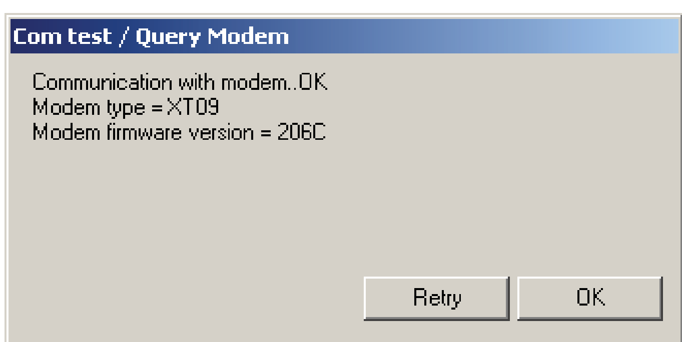

Fig 21: Result of the test/query of a modem

3.4. XBee mesh networks

Mesh network is a type of network topology in which a device (node) transmits its own data as well as serves as a relay for other nodes. It can be a full or partial mesh topology. In the full mesh topology, each node (workstation or other device) is connected directly to each of the others. In the partial mesh topology, some nodes are connected to all the others, but some of the nodes are connected only to those other nodes with which they exchange the most data. Fig. 22 illustrates a full and partial mesh network. The connections within a mesh network can be wired or wireless:

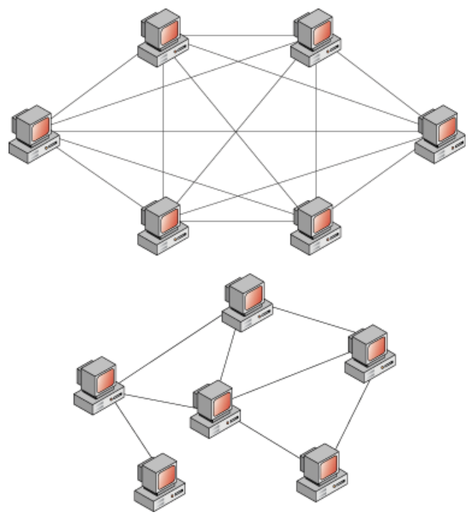

Fig 22: A full (top) and partial (bottom) mesh networks

A mesh network is reliable and offers redundancy. If one node can no longer operate, the others can still communicate with each other, directly or through one or more intermediate nodes. Mesh networks work well when the nodes are located at scattered points that do not lie near a common line. Star (broadcast) and cluster tree (tree) are other types of the XBee networks. Different types of the XBee networks can be combined.

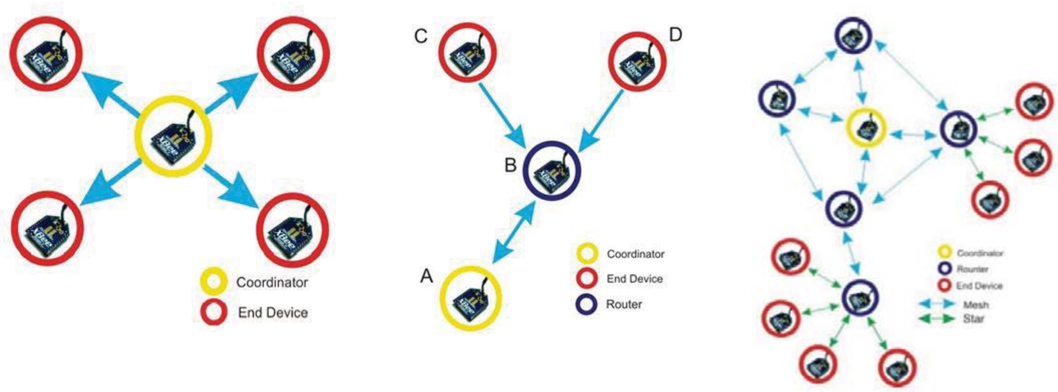

Fig 23: XBee star (left), tree (middle), combination of star and tree networks (right)

3.5. Creating a XBee mesh network

In order to create an XBee network (such as mesh network), at least two types of XBee modules are required: one coordinator and one router. The coordinator can be connected to the host PC via a USB dongle or explorer and the other one can be placed on the XBee shield[1] and connected to the Arduino micro-controller or a sensor device. On the XBee shield, there are two jumpers labeled as “XBEE/USB”. They are used to put the micro-controller in wireless or programming mode.

Fig 24: Arduino shield XBee-USB jumpers

The “Modem Configuration” tab in XCTU allows updating the XBee’s firmware.

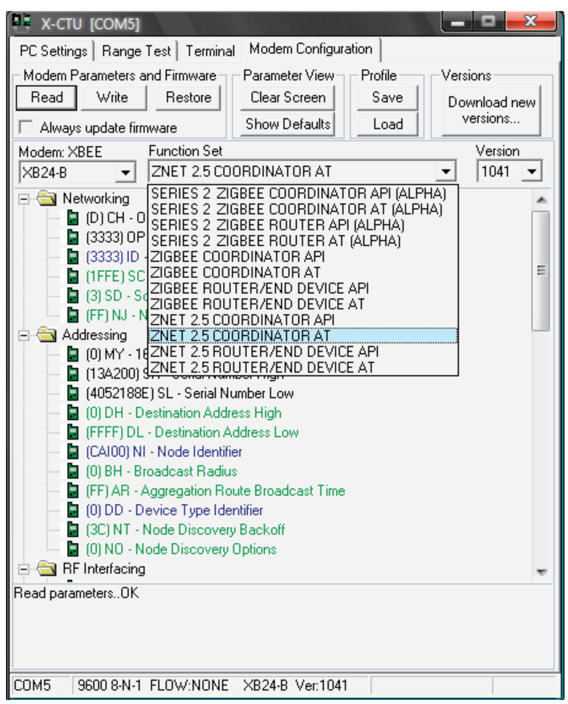

Fig 25: Updating the XBee firmware

[1] *The XBee shield allows connecting the XBee module to the Arduino micro-controller*

3.5.1. Setting up XBee coordinator and router

The following steps need to be taken in order to setup the XBee coordinator:

1. Select the "Modem Configuration" tab
2. Select a proper "Modem XBee" from the list
3. Change the firmware to "ZIGBEE ROUTER AT"
4. Set a PAN ID (for example 100)
5. Setup the destination by setting DH = 00 and DL = FFFF
6. Select "Always Update Firmware" and then update the firmware (Write)

The above steps need to be taken in order to setup the XBee router, except, in step 3, the firmware must be set to "ZIGBEE END DEVICE AT". Fig. 26 shows the require steps to setup the XBee Router and XBee End Device:

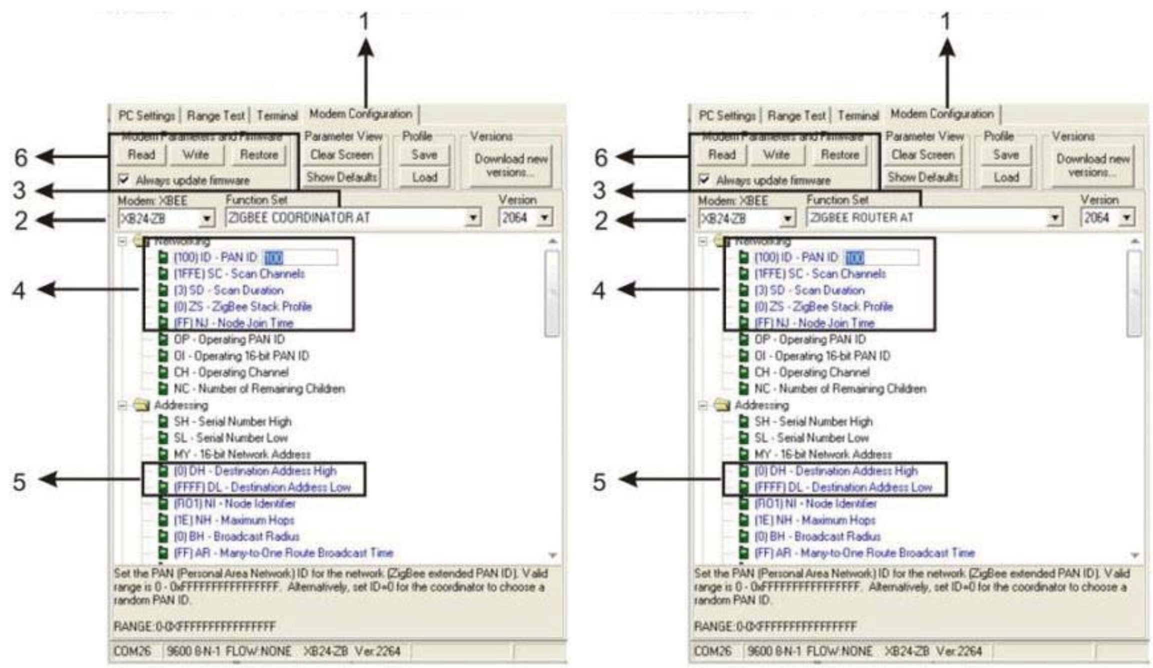

Fig 26: Setting up XBee coordinator and router

3.5.2. Testing the XBee network

The "Terminal" tab allows to test the XBee by sending AT commands. Fig. 27 shows a set of few simple commands to check the XBees:

Fig 27: Testing the XBee

- "+++" command will check the presence of the XBee by responding an "OK" prompt.
- The "ATVR" command will check the firmware version on the XBee.
- The "ATID" command will check the PAN network ID that the XBee is using. The PAN ID can be change to a unique number if the XBee is use in a place where other XBee's are using.
- The "ATNI" command checks the node identifier. The XBee will response with "Router1" of whatever unique node identifier is set for the XBee.
- The "ATCN" will exit the command mode.

When using the ZNet 2.5 firmware, routers or end devices can communicate with the coordinator by default. The coordinator sends the serial data to the XBee router connected and receives the data transmitted by the end device or router and reads them into the computer. Fig. 28 shows a sketch of Arduino program for testing the communication[1]:

[1] *To know more about Arduino micro-controller, visit section 4 - Hardware*

```
/*  Serial Test code
    Sends "testing..." over the serial connection once per second
    while blinking the LED on pin 13. Used for testing serial devices
    such as the XBee.

    Adapted from the SoftSerial Demonstration code
*/

#define ledPin 13
byte pinState = 0;

void setup()  {
  pinMode(ledPin, OUTPUT);
  Serial.begin(9600);
}

void loop() {

  Serial.println("testing...");
  // toggle an LED just so you see the thing's alive.
  toggle(13);
  delay(1000);

}

void toggle(int pinNum) {
  // set the LED pin using the pinState variable:
  digitalWrite(pinNum, pinState);
  // if pinState = 0, set it to 1, and vice versa:
  pinState = !pinState;
}
```

Fig 28: Sample Arduino sketch for testing communication

The program prints the message “testing...” on the terminal window and blinks the LED on pin 13 of the Arduino micro-controller. Once the sketch is loaded to the Arduino micro-controller, with the coordinator XBee still connected to the computer, the message “testing…” is displayed repeatedly on the “Terminal” tab of the X-CTU software.

3.6. Standalone XBee benefits and limitations

Each ZigBee radio (for example XB24-Z7WIT-004) has the capability to directly gather sensor data and transmit them without the use of an external micro-controller. In addition, the XBee offers some simple output functions so that basic actuations can also take place without an external micro-controller being present. For example, it is possible to send digital information directly to a standalone XBee radio to turn on a light or start up a motor. These independent inputs/outputs functions are named as “XBee direct” in order to distinguish them from the use of input and output that happens in conjunction with an external micro-controller.

By avoiding using an external micro-controller, the overall size of the project will be reduced, enabling the sensors to fit into tight spaces. It also reduces the weight of the sensors, which can be important if the system is aimed to be attached to a kite, balloon, or worn on the body. When it comes to wearable sensor, lighter is usually better. Omitting an external micro-controller also reduces the power consumption. This is a great advantage for those projects runs on batteries. Of-course, eliminating the external micro-controller means reducing the overall cost especially in the sensor networks with hundreds of nodes. Finally, using the XBee alone is sometimes the least-complicated approach to a project.

Projects that use the XBee alone for their inputs/outputs features may face significant limitations compared to projects that incorporate an external micro-controller. The XBee has limited input and output pins, with no simple way to extend them. The single biggest limitation is that the basic standalone XBee radio does not allow access to any kind of logic. This means that no decisions can be made on the local device and no standalone operations can be performed besides transmitting the data or changing the state of digital pins as the result of remote commands. The XBee series-2 hardware that the ZigBee firmware requires does not currently support analogue output, which means it cannot be employed to dim a light or control the speed of a motor without additional electronic components. Although the new variations of XBee radios incorporates a second micro-controller to allow some forms of local logic, this comes with an additional cost such as using special programming methods and requires knowledge of C and/or assembly programming which are both lower-level in comparison to the Arduino micro-controller [54].

3.7. RF modules

RF modules are low-cost RF links devices. They can be used to transmit position data, temperature data, and even current program register values wirelessly to the receiver. These modules have up to 500 feet (about 152 meters) range in open space. The transmitter operates from 2V to 12V. The range can be extended by increasing the voltage. The transmission occurs at the rate of 1Kbps to 10Kbps. An RF receiver operating at the same frequency as the transmitter receives the transmitted data. These modules are used extensively and directly interface with the micro-controller.

In theory, what the RF transmitter 'sees' on its data pin is what the receiver outputs on its data pin. It will have an instant wireless data connection if it configures the Universal Asynchronous Receiver/Transmitter (UART[1]) module on a Peripheral Interface Controller (PIC[2]). The typical range is 500 feet for an open area. This is an Amplitude-Shift Keying (ASK[3]) transmitter module with an output of up to 8mW depending on power supply voltage. The transmitter is based on Surface Acoustic Wave (SAW) resonator and accepts digital inputs, can operate from two to 12V-DC, and makes building RF enabled products very easy. The RF modules:

- Operate within the range of 315MHz to 2.4GHz
- Have a range up to 500 feet in open space dependent on transmitter power supply
- Have a data transfer rate of 2400bps to 4800bps
- Are low-cost, small in size and light in weight

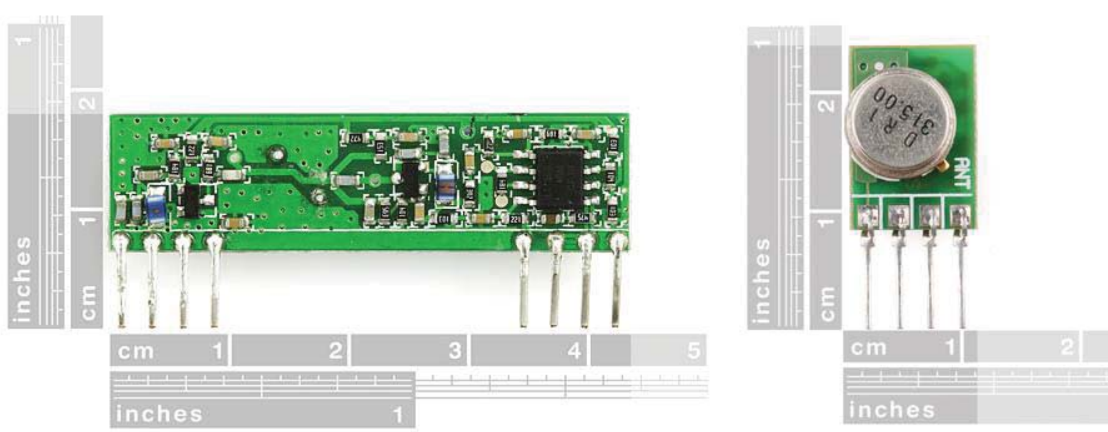

Fig 29: KLP/KLPA RF modules: receiver (left) and transmitter (right)

[1] *UART is a piece of computer hardware that translates data between parallel and serial forms. UARTs are commonly used in conjunction with communication standards*

[2] *PIC is a family of Harvard architecture micro-controllers made by micro-chip technology*

[3] *ASK is a form of modulation that represents digital data as variations in the amplitude of a carrier wave*

3.7.1. RF modules characteristics

The LaiPac (LP) modules provide a simple and straightforward transmitter/receiver pairs. According to its datasheet, these modules have the following characteristics:

LaiPac Model	Frequency range	Data rate	Operation voltage (Transmitter)	Operation voltage (Receiver)
TLP/RLP 434	315, 418, 434MHz	2,400 bps	2-12V	4.5-5.5V
TLP/RLP 434-A	315, 418, 434MHz	4,800 bps	2-12V	3.3-6V
TLP/RLP 916-A	915MHz	200 kbps	2-12V	2.7-5V
TLP/RLP 916-F	915MHz	40 kbps	2-12V	2.7-5.5V

Table 3: KLP/KLPA RF modules characteristics

Fig. 30 shows the pin layout of transmitter and receiver Laipac (T/R LP) modules:

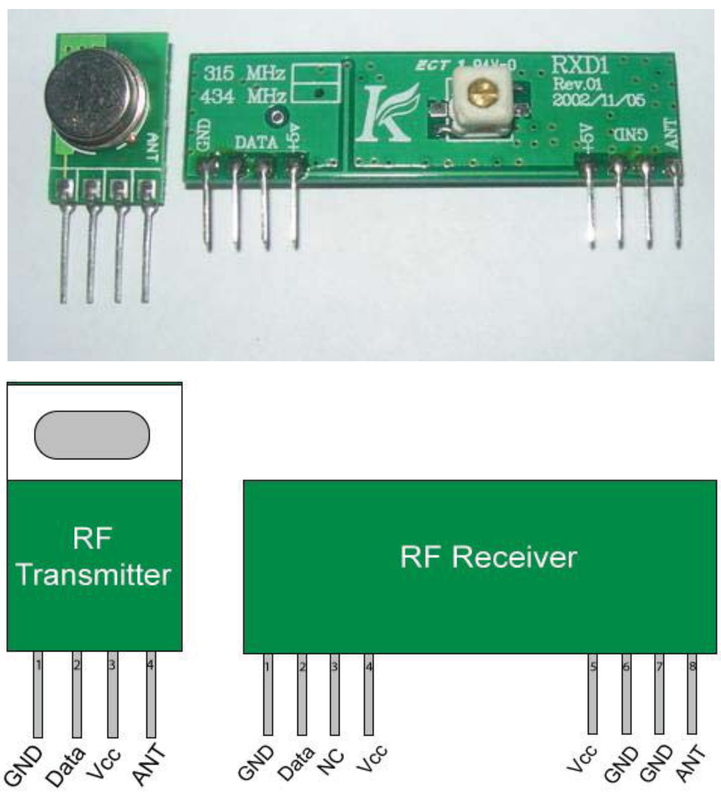

Fig 30: T/R LP modules

These devices are simple pass-through integrated circuits. This means that as long as they are setup with a baud-rate within an acceptable range (whatever pair of devices that are using), then the transmitter starts sending bytes to the receiver. In other words, the transmitter just sends the data out and the receiver will receive them.

3.7.2. Setting-up the RF modules

As shown in Fig. 30, the transmitter module has four pins while the receiver has six. The transmitter, transmits one byte at a time at the given baud rate. It needs an antenna and a power supply to starts transition. Fig. 31 and Fig. 32 show the simple schematic diagram of connecting the RF transmitter to the ATmega328 micro-controller and its connection to the Arduino micro-controller[1]:

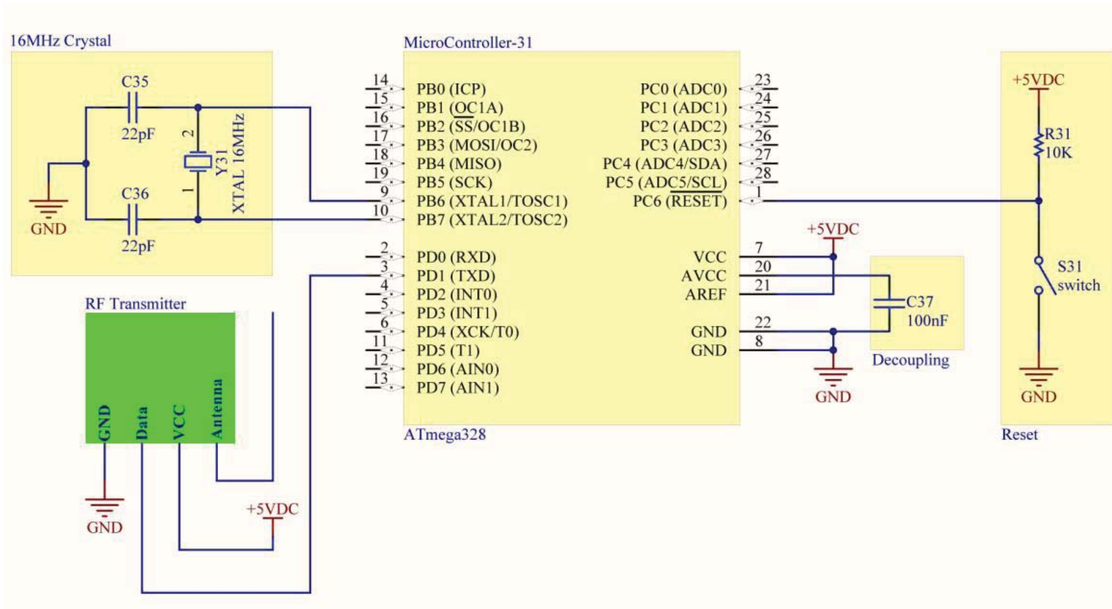

Fig 31: RF transmitter schematic

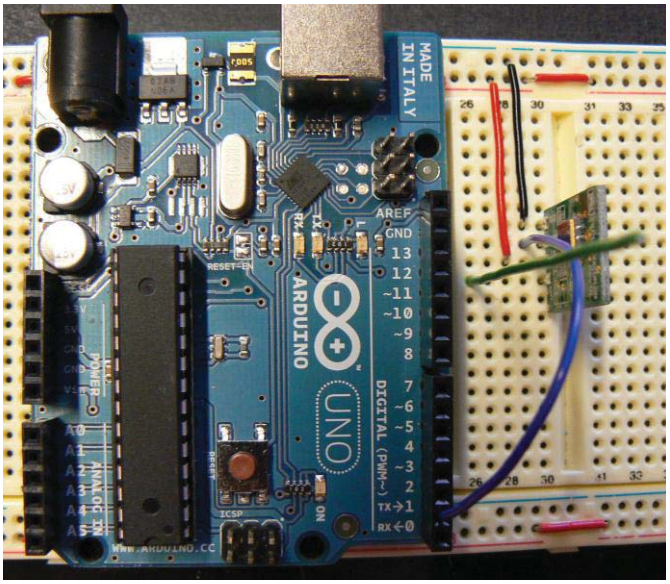

Fig 32: RF transmitter and Arduino UNO connections

[1] 4.2. Arduino micro-controller

At the receiver side, from the left, pin 1 (GND) connects to ground. Pin 2 (data) sends the incoming byte from the transmitter out to the micro-controller. Pin 3 needs no connection, but can be taken to ground. Pins 4 and 5 (Vcc) are connected to the power. Pins 6 and 7 (GND) are connected to ground and finally pin 8 (Antenna) is an optional antenna. Fig. 33 and Fig. 34 show the simple schematic diagram of connecting the RF receiver to the ATmega328 micro-controller and its connection to the Arduino micro-controller:

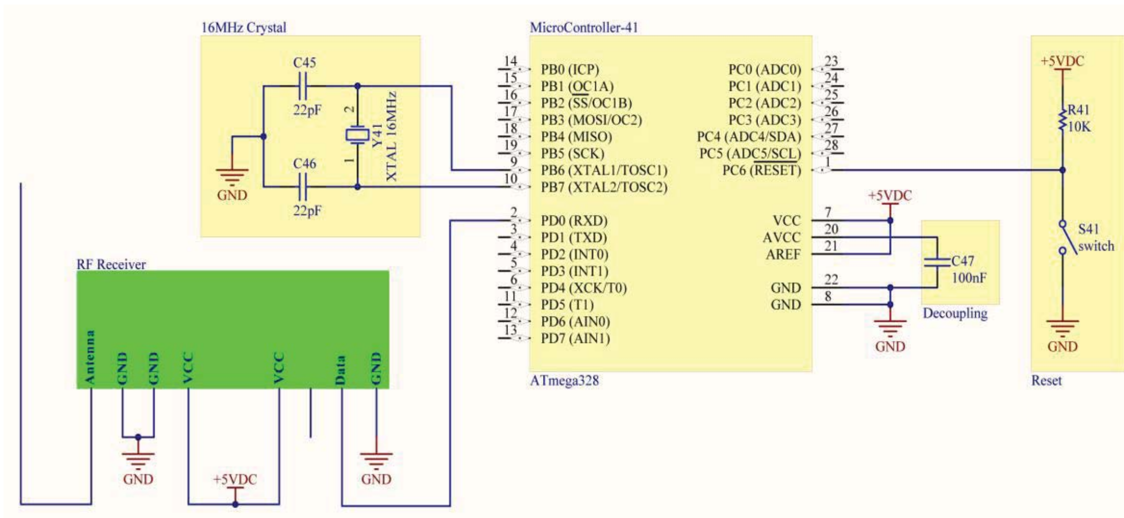

Fig 33: RF receiver schematic

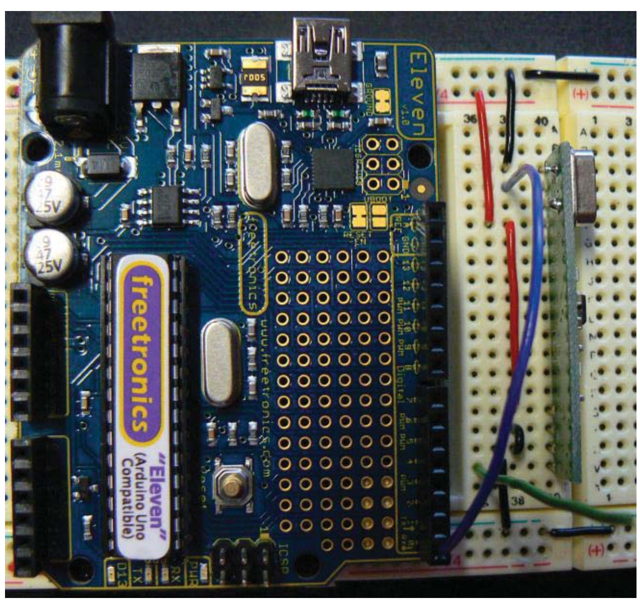

Fig 34: RF receiver and Arduino Eleven connections[1]

[1] *Arduino Eleven is a similar to the Arduino UNO except it uses Mini-USB connections instead of a normal USB port*

3.7.3. RF module antenna length

The RF modules operate within the range of 315MHz to 2.4GHz. Assume the frequency is about 433MHz. This frequency produces 433 million little sine waves per second:

$$Frequency(Hz) = \frac{cycle}{\sec ond}$$

Equation 1: Frequency definition

To find out how many seconds are in a cycle length:

$$Time(\sec) = \frac{\sec ond}{cycle} = \frac{1}{Frequency} = \frac{1}{433{,}000{,}000} = 2.3 * 10^{-9}\, s \sim 2.3ns$$

Equation 2: Time and frequency relationship

This means there is a 2.3ns in one cycle, which they are traveling at the speed of light (approximately $C = 3*10^{8} \frac{meter}{\sec ond}$). Therefore, the following equation is used to calculate the length of each cycle or wavelength:

$$\lambda = C * T = 3*10^{8} * 2.3*10^{-9} = 0.69 meters = 69cm$$

Equation 3: Calculating the wave-length

It is recommended to use the quarter of the wavelength for RF antenna[1]. Therefore, the antenna length can be calculated as:

$$Length = \frac{69}{4} \approx 17.25cm$$

Equation 4: Calculating the antenna length

Table 4 shows the antenna length for different operating frequencies:

Operating Frequency	Best Antenna Length
315MHz	23.81 cm
418MHz	17.94 cm
433MHz	17.28 cm
2.4GHz	0.03 cm

Table 4: Antenna length for different operating frequencies

[1] *Reference: www.solidremote.com/support/rf-module-external-antenna-design*

3.8. XBee and RF modules comparisons

A comparison metrics is needed to compare the three prototypes. The metrics items are chosen in terms of requirements for the final sensor device. The final product must be small, low-cost, light in weight, easy to program and maintain with a high degree of reliability:

Characteristics	XBee Modules	RF Modules
Maximum range (open space)	1.6 km	150 meters
Maximum Frequency	2.4GHz	915MHz
Maximum data transfer rate	250Kbps	40Kbps
Network ability/security	Yes/High	No/High
Effect of external noises	Very low	Very high
Power consumption mode	Yes	No
Data transition reliability	High	Low
Programming/synchronization	Easy/not needed	Difficult/needed
Can be stand-alone	Yes	No
Antenna length	0.03cm @ 2.4GHz	8cm @ 915MHz
Receiver operating voltage	3.3 volts	2.7-6 volts
Transmitter operating voltage	3.3 volts	2-12 volts
Unit cost (approximately)	$60 NZ	$15 NZ

Table 5: XBee and RF modules comparisons

Table 5 displays the results of the comparison between the XBee and RF modules. Although the RF sensors are much cheaper, smaller and lighter, they have some limitations. Each RF transmitter device has a supply voltage range from 2V to 12V. The higher the voltage, the stronger the signal will be. Commonly, the micro-controller and other circuitry may be running at 5V, so it may need to route a separate line of power (for example separate power supply). In addition, the use of an antenna will increase the effectiveness of the wireless communication. A simple wire will do the job, but it is recommended to use the antennas specifically designed for this purpose. Programming the RF modules is much more expensive than XBee modules and synchronizing them is difficult. The baud rates of the RF modules are much lower than XBee modules and each transmitter and receiver needs separate micro-controllers to be connected to. The RF modules are extremely sensitive to external noises and require additional electronics circuitry to filter them. This issue will reduce the reliability of transmitted data, which is crucial in any wireless devices. As this device is transmitting the human health data, it might be very risky. The main factors, which affect the RF module operating distance, are as follows:

- The transmitter power: the higher power extends the communication distance but is also prone to cause interference with other RF devices
- The antenna using: a long antenna will increase the remote distance
- Obstacles: the labeled remote distance is normally measured in open-air (line of sight distance without any interference). But often there are obstacles such as walls and floors that greatly absorb the radio wave signals, so the remote distance is much nearer

In addition, the RF modules:

- cannot make a network like XBee
- do not have security
- do not have energy consumption mode
- communicate in a single way while XBees communicate bi-directionally
- do not have sleep mode capability for saving power when it does not need to be operated

In conclusion, the XBee module is chosen based on the following factors:

- Range
- Frequency
- Data transfer rate
- Reliability of transmitted data
- Low power consumption
- Ease of programming and synchronization

CHAPTER 4 – HARDWARE

Many patients who require constant health monitoring prefer the comfort of at-home healthcare compared to costly and inconvenient hospital care. The main difficulty with home healthcare is enabling patients to provide accurate and timely health data to the healthcare professionals. The objective is to create a cheap, reliable, lightweight and wearable wireless heart rate and temperature sensor. The sensor is expected to be able to transmit data wirelessly to the host computer or healthcare service robot.

4.1. Micro-controller

A microcontroller is a computer. Microcontrollers are "embedded" inside some other device so that they can control the features or actions of the product. They are dedicated to one task and run one specific program. Microcontrollers are often low-power devices (a battery-operated microcontroller consumes 50 mill-watts). Most micro-controllers are general purpose. They have additional parts that allow them to control the external devices. In general, designers use micro-controllers to gather input from various sensors, process this input into a set of actions and use the output mechanisms on the Microcontroller to do something useful.

4.2. Arduino micro-controller

After an intensive research on the available micro-controllers, Arduino micro-controller is selected as a suitable choice. “Arduino is an open-source electronics prototyping platform based on flexible, easy-to-use hardware and software. It's intended for artists, designers, hobbyists, and anyone interested in creating interactive objects or environments“ (Arduino official website, retrieved 2011).

Arduino can sense the environment by receiving data from a wide variety of sensors. It can controls light, motors, and other actuators and devices. The on-board micro-controller chip can be programmed using the Arduino programming language[1] based on Wiring[2] and the development environment based on Processing[3]. Arduino projects can communicate with the

[1] *Arduino programs are divided into* structure, values *(variables and constants) and* functions*. To see the list of commands visit arduino.cc/en/Reference/HomePage*

[2] *Wiring is an open-source programming environment exploring the electronic arts, tangible media, teaching and learning computer programming and prototyping with electronics: www.wiring.org.co*

[3] *Processing is an open-source programming language and environment to create images, animations, and complex interactions: www.processing.org*

computer directly or can be used stand-alone. The micro-controller software is open-source and free to use and widely supported by the open-source community. The hardware reference designs (such as Schematic diagrams) are also available under an open-source license and free to modify, change and adapt to needs.

Arduino hardware and its software, simplify the amount of work on both hardware development and software programming. It has an on-board power supply and reset circuitry. It also has circuitry that allows micro-controller to program and communicate over USB. In addition, the input/output (I/O) pins of the micro-controller are typically fed out to sockets/headers for ease of access. These pins may vary a bit depending on the specific model of Arduino. In terms of software, it provides a number of libraries to make micro-controller programming easy. For example, it has functions to control and read the I/O pins compared to traditional access to I/O pins. In addition, the more useful functions such as being able to set I/O pins to Pulse-Width Modulation (PWM[1]) at a certain duty cycle using a single command.

The advantages of using Arduino are as follows:

- Cheap, small and a great choice for quick prototyping
- Being able to just hook up an LCD display in a matter of minutes and program it using built-in Arduino Liquid Crystal Library
- There are a lot libraries freely available that allow concentrating on testing the idea instead of building supporting circuitry or writing huge amount of low level programming
- Has a great community of developers and users
- Faster coding – avoid traditional and complex serial communication programming
- Easy-to-use subset of C/C++ - supports “multi-threading” and “interrupts”
- Support wide variety of add-on boards known as Shields which allow to different hardware to be connected to the Arduino easily

4.2.1. Arduino micro-controller boards

Arduino micro-controller comes in different types of boards. These boards are designed for different purposes and in different sizes. Fig. 35 is one of the latest revision of the basic Arduino USB development board called UNO. It connects to the computer with a standard USB cable and can be extended with a variety of shields. It has 28-pins ATmega328 chip on-board. The micro-controller chip is removable and therefore can be used as a programmer. That means that a new chip can be placed on the board, programed and removed and then placed on the target device to run. In addition, the development board enables the use of different shields, power sources (through USB port or power supply) or even connect to another Arduino board.

[1] *“PWM is a commonly used technique for controlling power to inertial electrical devices, made practical by modern electronic power switches”. Reference: wikipedia.org/wiki/Pulse-width_modulation*

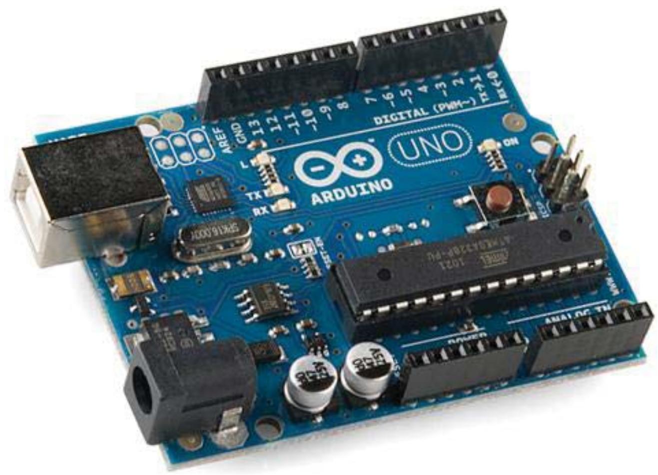

Fig 35: Arduino UNO

4.2.2. Arduino features

The Arduino UNO micro-controller is based on the ATmega328. It has:

- 14 digital I/O pins (6 can be used as PWM outputs) + 6 analogue inputs
- a 16MHz crystal oscillator
- a USB connection to connect to computer as well as to supply the power
- a DC power jack
- an ICSP header and a reset button

It supports a wide variety of AC-to-DC adapters or batteries to get started. “The UNO does not use the FTDI USB-to-serial driver chip. Instead, it features the ATmega8U2 programmed as a USB-to-serial converter” (Arduino official website, retrieved 2011).

Arduino UNO micro-controller (from Arduino official website)	
Operating Voltage	5V
Input Voltage (recommended)	7-12V
Input Voltage (limits)	6-20V
Digital I/O Pins	14 (of which 6 provide PWM output)
Analogue Input Pins	6
DC Current per I/O Pin	40 mA
DC Current for 3.3V Pin	50 mA
Flash Memory	32 KB (ATmega328) - 0.5 KB used by boot-loader
SRAM	2 KB (ATmega328)
EEPROM	1 KB (ATmega328)
Clock Speed	16 MHz

Table 6: Arduino UNO summary

- Power: The Arduino UNO board can be powered via the USB connection or an external power supply. The power source is selected automatically by the board. Non-USB power can be an AC-to-DC adapter or battery. The board can operate with an external supply limit from 6V to 20V. However, the input voltage below 7V causes the 5V pin to supply less than 5V and therefore the board becomes unstable. If using more than 12V, the voltage regulator may overheat and damage the board. Therefore the recommended voltage range by Arduino is between 7V to 12V.
- Memory: The ATmega328 has 32KB flash memory which 500 bytes is used for the boot-loader. It also has 2KB of Static Ram (SRAM) and 1KB of EEPROM[1]. The EEPROM can be read and write with the Arduino EEPROM library.
- Inputs and Outputs: Each of the 14 digital I/O pins on the UNO can be used as an input or output and operates at 5V. Each pin can provide or receive a maximum of 40mA and has an internal pull-up resistor of 20-50KΩ (disconnected by default) and can be accessed with a set of simple functions such as pinMode(), digitalWrite(), and digitalRead()[2].
- Communication: The Arduino UNO can communicate with a computer, another Arduino, or other micro-controllers using ATmega328 that provides UART TTL (5V) serial communication. It is available on digital pins 0 (RX) and 1 (TX). "An ATmega8U2 on-board, channels this serial communication over USB and appears as a virtual communication port to software on the computer. The "8U2 firmware uses the standard USB COM drivers, and no external driver is needed" (Arduino website, retrieved 2011).
- Programming: The Arduino UNO can be programmed with the Arduino software. The ATmega328 on the Arduino UNO comes with a pre-burned boot-loader that allows programs to be upload to the micro-controller without the use of an external hardware programmer device. "It communicates using the original 8Bit STK500 communication protocol" (Atmel website, retrieved July 2011).

[1] Electrically Erasable Programmable Read-Only Memory (EEPROM) is a type of non-volatile memory used in electronic devices to store small amounts of data that must be saved permanently in case of power is removed

[2] For commands details visit: arduino.cc/en/Reference/HomePage

4.2.3. Arduino XBee Shield

The XBee shield allows an Arduino board to communicate wirelessly using ZigBee protocol. The shield breaks out each of the XBee's pins to a through-hole solder pad. It also provides female pin headers that allow to use digital pins 2 to 7 and the analogue inputs, which are covered by the shield.

The XBee Shield simplifies the task of interfacing an XBee with the Arduino board. This unit works with all XBee modules including the Series 1 and Series 2.5, standard and Pro version. Power is taken from the 5V pin of the Arduino and regulated on-board to 3.3VDC before being supplied to the XBee. The shield also takes care of level shifting on the Digital Input pin (DIN) of the XBee. The XBee shield includes LEDs to indicate power, activity on DIN, Digital Output (DOUT), Received Signal Strength Indication (RSSI) and associate indicator pin (DIO5) of the XBee. Installing the XBee shield on top of Arduino will cover the reset button on the micro-controller board. Therefore the Arduino's reset button is brought out on the shield.

Fig 36: XBee shield and XBee module

4.3. Temperature sensor

An analogue temperature sensor is a chip that tells what the ambient temperature is. These types of sensors use a solid-state technique to determine the temperature. They use the fact that as the temperature increases, the voltage across the diode increases at a known rate. This is actually the voltage drop between the base and emitter of a transistor. By precisely amplifying the voltage change, it is easy to generate an analogue signal that is directly proportional to the temperature.

4.3.1. Body temperature study

One of the important signs of health is the body temperature. Human body temperature (also known as “normothermia” or “euthermia”) vary and depends on the place in the body at which the measurement is made, the time of day and the person’s level of activities. There is no single number that represents a normal or healthy temperature for all people under all circumstances.

Different parts of the body have different temperatures. The measurements taken directly inside the body cavity are typically slightly higher than oral measurements, and oral measurements are somewhat higher than skin temperature. The commonly accepted average core body temperature (taken internally) is between 37.0°C and 37.7°C. The typical oral (under the tongue) measurement is slightly cooler, at 36.8±0.7°C. The time of day, environment temperature and other circumstances also affect the body temperature. The body temperature also changes when a person is hungry, sleepy, or cold (World of Sports Science, Retrieved 2011).

- Variations due to measurement methods: Different methods that are used for measuring the temperature produce different results. Generally, oral, rectal, gut and core body temperatures, although slightly different, are well-correlated. Oral temperatures are influenced by drinking, chewing, smoking, and breathing. Cold drinks or food reduce oral temperatures while hot drinks, hot food, chewing, and smoking raise oral temperatures[1].

  Auxiliary (armpit), tympanic (ear), and other skin-based temperatures are poorly correlated with core body temperature. “The body uses the skin as a tool to increase or decrease core body temperature, which affects the temperature of the skin. Skin-based temperatures are more variable than other measurement sites”[1]. Skin temperatures are also more influenced by outside factors such as clothing and air temperature.
- Variations due to outside factors: Many outside factors affect measuring body temperature. Exercise raises body temperature. In adults, a noticeable increase usually

[1] *First Aid and Emergencies. From firstaid.webmd.com/body-temperature: Retrieved July 2011*

requires strenuous exercise or exercise sustained over a significant time. Children develop higher temperatures with milder activities, like playing. Psychological factors also influence body temperature: a very excited person often has an elevated temperature. Sleep disturbances also affect temperatures. Normally, body temperature drops significantly at a person's normal bedtime and throughout the night. Short-term sleep deprivation produces a higher temperature at night than normal, but long-term sleep deprivation appears to reduce temperatures. Insomnia and poor sleep quality are associated with smaller and later drops in body temperature. Similarly, waking up unusually early, sleeping in, jet lag and changes to shift work schedules may affect body temperature[1].

4.3.2. TMP36 temperature sensor

There are many temperature sensors in the market. TMP36 temperature sensor[2] is an analogue device. It has a range from -40 to +150 °C. It does not require a negative voltage to read sub-zero temperatures. According to its datasheet, TMP36 has the following characteristics[3]:

- TO-92 package (about 0.2" x 0.2" x 0.2")
- Low voltage operation (2.7 V to 5.5 V)
- Calibrated directly in °C
- 10 mV/°C scale factor (20 mV/°C on TMP37)
- ±2°C accuracy over temperature
- ±0.5°C linearity
- Specified −40°C to +125°C
- Less than 50µA quiescent current
- Shutdown current 0.5µA max
- Low self-heating

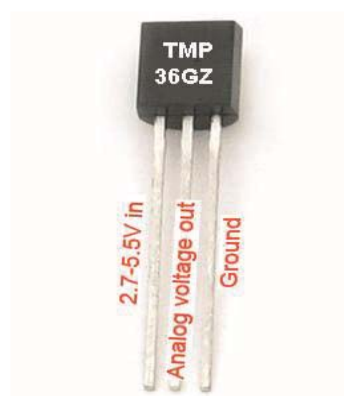

Fig 37: TMP36 temperature sensor

4.3.3. TMP36 and Arduino micro-controller

The temperature from TMP36 sensor can be read by connecting the output pin of the sensor directly into an analogue input of Arduino micro-controller. It requires any voltage supply from 2.7V to 5.5V. No matter what the voltage supply is, the analogue voltage reading will range from 0V (ground) to about 1.75V.

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[1] *First Aid and Emergencies. From firstaid.webmd.com/body-temperature: Retrieved July 2011*

[2] *Appendix I: TMP36 temperature sensor datasheet*

[3] *These information are extracted directly from TMP36 datasheet*

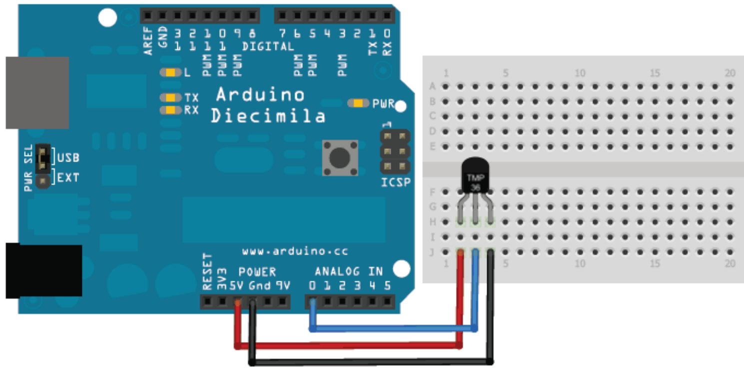

Fig 38: TMP36 and Arduino connections

No matter what temperature is used, it is required to be calibrated in order to get the correct reading.

4.3.3.1. Temperature calibration techniques

"Calibration is a process of aligning what the formulas say with what the real devices actually do. This involves taking some accurate measurements" (Microstar Laboratories Inc, retrieved June 2011). There are four adjustments that a good calibration can provide.

- Offset: In this technique, all voltages are measured with respect to a reference. Any displacements in these voltages will produce consistent errors that affect all measurements. Offset corrections make these errors as small as possible.
- Gain: The voltage that is measured is not really the voltage present on the sensor device. Amplifiers between the sensor and the digitizing converter change the signal level. To recover the sensor information, it must restore the data to the original level accurately. Uncorrected gain errors tend to produce measurement errors that change consistently across the operating range.
- Linearization: The relationship between measured voltage and sensed temperature is in general nonlinear and dependent on the physical properties of each sensor type. "Over a limited range, a simple linear function is often a sufficient approximation, but a more complicated curve is necessary to describe the relationship accurately. Generalized curves defined by standards help, but they won't match any individual device perfectly" (Microstar Laboratories Inc, retrieved June 2011). For best accuracy, it is necessary to calibrate, and adjust the coefficient values of the conversion function.
- Unit scaling: After applying the offset, gain, and linearization corrections, the results might not be in the most useful form. It will be more meaningful to convert the results to a common and useful representation. For example, present all temperature measurements in degrees C. "It is not always possible to control what a sensor does directly. It responds based on its physical properties. But it is possible to some extent

control what the sensor measures" (Microstar Laboratories Inc, retrieved June 2011). It can be established a set of temperature levels that span the operating range, and measure those levels with a laboratory-grade temperature standard. For each of those measured temperature points, observe the response level of the sensor. "If we construct a curve that passes through these points then we will have a very good calibration specialized for the individual sensor" (Microstar Laboratories, Inc, retrieved June 2011).

4.3.3.2. TMP36 temperature sensor calibration

The TMP36 temperature sensor does not act like a resistor. Because of this, there is really only one way to read the temperature value from the sensor by connecting the output pin of the sensor directly into an analogue input of the micro-controller. After connecting the TMP36 temperature sensor to micro-controller, the voltage reading from the sensor needs to be converted to a temperature.

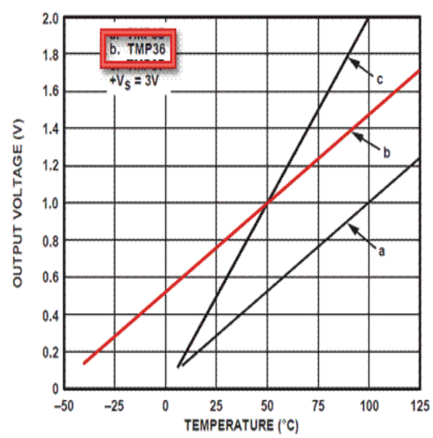

Fig 39: Output voltage vs temperature

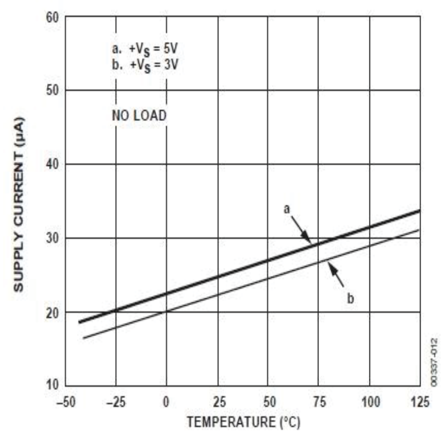

Fig 40: Output current vs temperature

The Arduino micro-controller has 10-bit resolution (2^{10} =1024). If the input voltage to the sensor is X volts, and connecting the sensor output directly into an analogue pin of the micro-controller, then the following formulas can be used to turn the 10-bit analogue reading into a temperature:

$$Voltage = (reading\_from\_ADC) * (X * 100/1024)$$

Equation 5: Convert ADC value to voltage

The following equation converts the number 0-1023 from the ADC into 0-X thousands mV:

$$Temperature\_in\_^{\circ}C = [(analog\_voltage\_in\_mV) - X * 100]/10$$

Equation 6: Convert voltage to temperature

For example, if the analogue voltage is 1V (1000mV) and the supply voltage to the sensor is 5V, then the temperature is ((1000 mV - 500) / 10) = 50 °C

A digital thermometer (Fluke 51 K/J[1]) is used to check the readings from TMP36 temperature sensor. Different types of objects are examined by Fluke digital thermometer and TMP36 temperature sensor (after calibration) and the results are recorded:

Object	Fluke digital thermometer	TMP36 Sensor	Difference
Room temperature	24.98	24.01	0.97
Skin temperature - 1	32.64	31.06	1.04
Skin temperature - 2	33.87	29.84	1.03
Cup of tea	68.06	67.01	1.05
Aluminum surface	16.70	15.82	0.88
CPU surface while working	54.11	53.03	1.08

Table 7: Sample temperature readings

4.3.4. Estimation of mean-body temperature from skin temperature

"Since the specific heat of human tissue is relatively well established, body heat content can be calculated from mean-body temperature [MBT]. Mean-body temperature, defined as the mass-weighted average of tissue temperatures throughout the body, is thus a fundamental characterization of a person's thermal status"[2].

Even in a moderate environment, average temperature of the peripheral thermal compartment is between 2 to 4°C less than core temperature [46]. However, this range may change from nearly zero to a large value depending on the severity of the environmental effect and the consequent vasomotor responses. "The preoperative period is dynamic and associated with substantial changes in the core-to-peripheral tissue temperature gradient and internal distribution of body heat" [46]. For example, induction of general anesthesia is associated with a substantial flow of heat from the core to peripheral tissues because anesthetics reduce the vasoconstriction threshold (triggering core temperature) by 2 to 4°C [47]. Vasoconstriction then recurs in patients who become sufficiently hypothermic, usually at a core temperature of approximately 34.5°C; this vasoconstriction constrains metabolic heat to the core thermal compartment and eventually restores the normal core-to-peripheral thermal gradient [48]. Core temperature is easy to measure. It is thus easy to determine average temperature of the core thermal compartment. On the other hand, peripheral tissue temperatures vary widely depending on the region, environmental characteristics and thermoregulatory vasomotor effect. "Direct

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[1] Fluke 51 is a high quality, high performance, single-channel Digital Thermocouple Thermometer with 1°C or 0.1°C (1°F or 0.2°F) resolution. www.ie2000.com/fluke51.html

[2] Estimation of Mean-body Temperature. From Mean-skin and Core Temperature. From www.ncbi.nlm.nih. gov/ pmc / articles/PMC1752199: Retrieved July 2011

measurement of peripheral tissue temperature is difficult, but can be accomplished by insertion of a sufficient number of needle thermocouples, combined with tedious calculations. This procedure is complex, painful, and risky"[1]. In 1935, Burton[2] proposed the calculation of MBT from core and skin temperature using the following formula:

$$MBT = \alpha * T_{core} + (1-\alpha) * T_{skin}$$

Equation 7: Burton's equation

The general form of the equation is based on the logic that core tissues are relatively homogeneous whereas skin temperature decreases from core to skin. The contribution of core temperature to mean-body temperature (α) can be estimated by simultaneously measuring the change in body heat content (in a calorimeter), core temperature and mean-skin temperature. Burton measured this value as 0.64. Therefore, the MBT can be estimated using the following equation:

$$MBT = 0.64 * T_{core} + 0.36 * T_{skin} - (T_{core} \cong 37^{\circ} C)$$

Equation 8: Mean body temperature with approximate alpha value

Others have used similar approaches to estimate the value of α . Table 8 shows the result of these studies:

Researcher	Value of Alpha	Environment
Hardy and DuBois [49]	0.7	Neutral
Stolwijk and Hardy [50]	0.7	Hot
Snellen [51]	0.8	During muscular work in a hot
Colin [52]	0.64	Neutral
Colin	0.79	Extremely warm

Table 8: Alpha value for Burton's equation by different studies

4.3.4.1. Temperature sensor testing and experiment

The aim of this experiment is to estimate the mean body temperature by applying Burton's equation (with $\alpha = 0.64$) to the TMP36 temperature sensor readings. For this reason, a group of 50 volunteers were examined and their body temperatures recorded using:

- TMP36 temperature sensor to read their skin temperature
- Omron "MC-246" digital thermometer[3] to record their internal body temperature

[1] *Estimation of Mean-body Temperature. From Mean-skin and Core Temperature. From www.ncbi. nlm. nih. Gov /pmc / articles/PMC1752199: Retrieved July 2011*

[2] *Burton AC. Human Calorimetry: The average temperature of the tissues of the body. J Nutr. 1935;9:261–280*

[3] *MC-246 digital thermometer: www.omronhealthcare.com/products/mc-246*

The null and its alternative hypothesis are setup up as follows:

H0: There is no difference between the mean of the two groups $(\mu_1 = \mu_2)$

H1: There is a significant difference between the mean of the two groups $(\mu_1 >> \mu_2)$

4.3.4.2. Digital thermometer vs TMP36 temperature sensor

In this experiment, the participant's body temperature is read using an Omron digital thermometer and a TMP36 temperature sensor. Both readings are recorded and the differences between the readings are calculated[1] and presented in Table 9 and Fig. 41:

	Degrees °C
Minimum	4.24
Maximum	9.88
Median	7.50
Average	7.31
Standard Deviation	1.57

Table 9: Omron digital thermometer vs TMP36 sensor readings

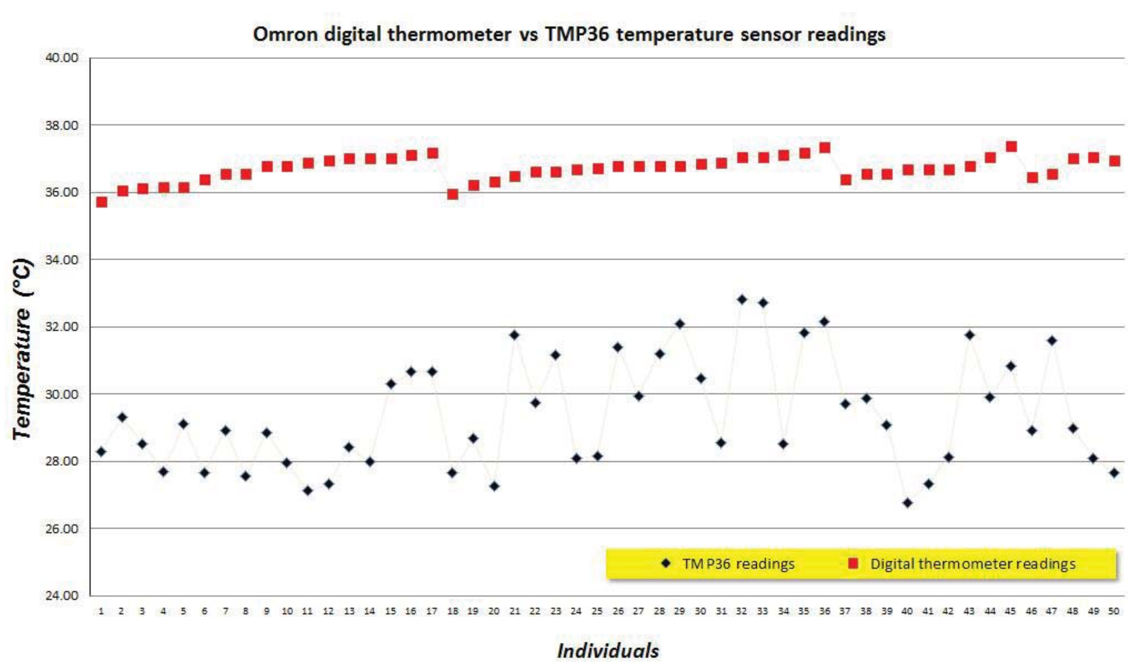

Fig 41: Omron digital thermometer vs TMP36 temperature sensor readings

[1] *Appendix D: Sensor data*

4.3.4.3. Applying the Burton's equation

The Burton's equation is applied to analyse the readings from the TMP36 temperature sensor. The output data together with the differences between the readings are shown in Table 10 and Fig. 42:

	Degrees °C
Minimum	0.27
Maximum	2.33
Median	1.30
Average	1.33
Standard Deviation	0.58

Table 10: Omron digital thermometer vs modified TMP36 sensor readings

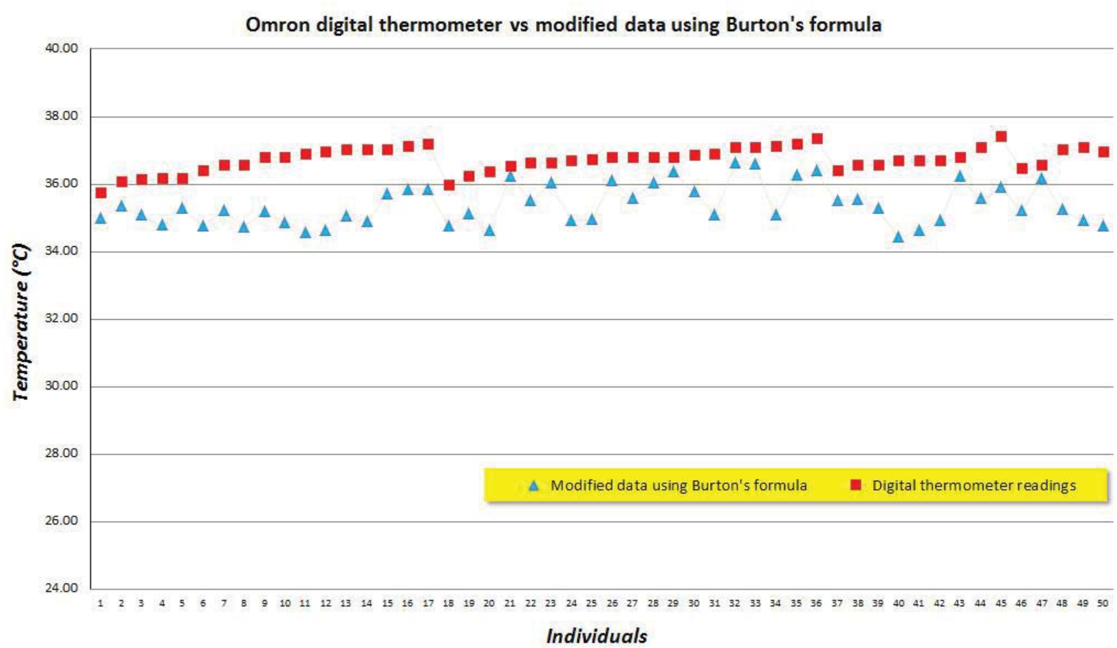

Fig 42: Omron digital thermometer vs modified data using Burton's equation

4.3.4.4. Temperature reading results and data analysis

The data collected in the previous two stages are plotted on the same graph to compare the changes more clearly.

	OMRON vs TMP36	OMRON vs modified TMP36
Minimum	4.24	0.27
Maximum	9.88	2.33
Median	7.50	1.30
Average	7.31	1.33
Standard Deviation	1.57	0.58

Table 11: Omron digital thermometer vs TMP36 and modified TMP36 sensor readings

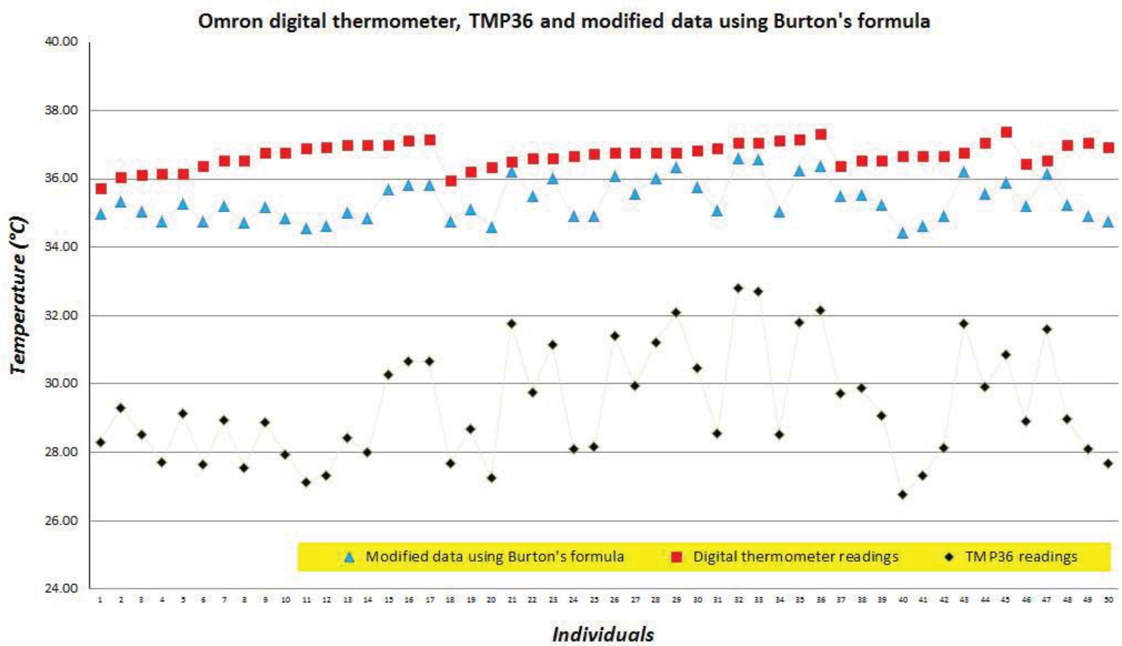

Fig 43: Omron digital thermometer, TMP36 and modified data using Burton's equation

	Variable 1	Variable 2
Mean	7.314720891	1.334855076
Variance	2.451540237	0.331871661
Observations	50	50
Pearson Correlation	0.917745047	
Hypothesized Mean Difference	0	
df	49	
t Stat	39.81612614	
P(T<=t) one-tail	2.77309E-39	
t Critical one-tail	1.676550893	
P(T<=t) two-tail	5.54617E-39	
t Critical two-tail	2.009575199	

Table 12: T-test - paired two samples for means

In order to assess whether the means of the two groups are statistically different from each other, the statistical "t-test" is used. The result of the analysis of the data is as shown in Table 12.

The p-value depends on a given sample and attempts to provide the strength of the test. It measures how much evidence exists against the null-hypothesis. If the null hypothesis is true and the chance of random variation is the only reason for sample differences, then the p-value is a quantitative measure to feed into the decision making process as evidence. It is possible to combine the p-value with the significance level to make a decision on the validity of the hypothesis. In such a case, if the p-value is less than a certain threshold (usually 0.05, sometimes a bit larger like 0.1 or a bit smaller like 0.01) then it rejects the null hypothesis. For the purpose of this test, the alpha value is set as $\alpha = 0.05$ (95% confidence interval). Considering the t-test analysis of the two groups, the p-value of the test is shown to be significantly smaller than the threshold $(p - value << \alpha)$. It can be concluded that there is not enough evidence to accept the null-hypothesis. Therefore, the null-hypothesis is rejected in favour of the alternative hypothesis.

In conclusion, the Arduino micro-controller software function, which measures the MBT, uses the Burton's equation in order to get the better estimation of human body temperature.

4.4. Heart rate sensor

Heart rate is measured by finding the pulse of the body. Plenty of non-invasive methods exist for electronically sensing the human heartbeat. This can be done acoustically (stethoscope or Doppler), mechanically (sphygmomanometer), electrically (EKG), and optically. An optical technique can exploits the fact that tiny subcutaneous blood vessels (capillaries) in any patch of skin (fingertip, ear lobe, etc.) furnished with a good blood supply, alternately expand and contract in time with the heartbeat. An ordinary infrared LED/phototransistor pair can sense this rhythmic change as small but detectable variations in skin contrast.

4.4.1. The principle of pulse oximetry

"Oximetry is the measurement of transmitted light through a translucent measuring site to determine a patient's oxygen status noninvasively"[1]. Oxygen binds to haemoglobin in red blood cells when moving through the lungs. It is transported throughout the body as arterial blood. A pulse oximeter uses two frequencies of light to determine the percentage of haemoglobin in the blood that is saturated with oxygen. The percentage is called blood oxygen saturation, or SpO_2. A pulse oximeter also measures and displays the pulse rate at the same time it measures the SpO_2 level. Pulse oximetry uses a light emitter with red and infrared LEDs that shines through a reasonably translucent site with good blood flow and a receiver (such as photo-detector) that receives the light that passes through the measuring site. Oxygenated haemoglobin absorbs more infrared light and allows more red light to pass through. Deoxygenated haemoglobin absorbs more red light and allows more infrared lights to pass through. Fig. 44 shows the wavelength of both red and infrared light used in pulse oximeters [53]:

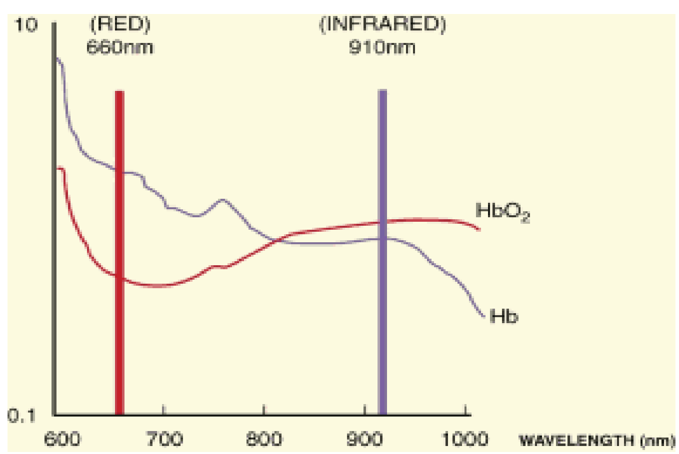

Fig 44: Infrared and red light wavelength

[1] *Reference: www.oximetry.org*

The best wavelength values for the infrared and red light are shown on the Fig. 44. Typical adult/paediatric sites are the finger, toe, pinna (top) or ear lobes. Infant sites are the foot or palm of the hand and the big toe or thumb [53]. There are two methods of sending light through the measuring site: Transmission and Reflectance.

In the transmission method, as shown in Fig. 45 (left), the emitter and detector are opposite each other with the measuring site in between. The light can then pass through the site. In the reflectance method as shown in Fig. 45 (right), the emitter and detector are next to each other on one side of the measuring site. The light bounces from the emitter to the detector across the site. The transmission method is the most common type used in pulse oximetery.

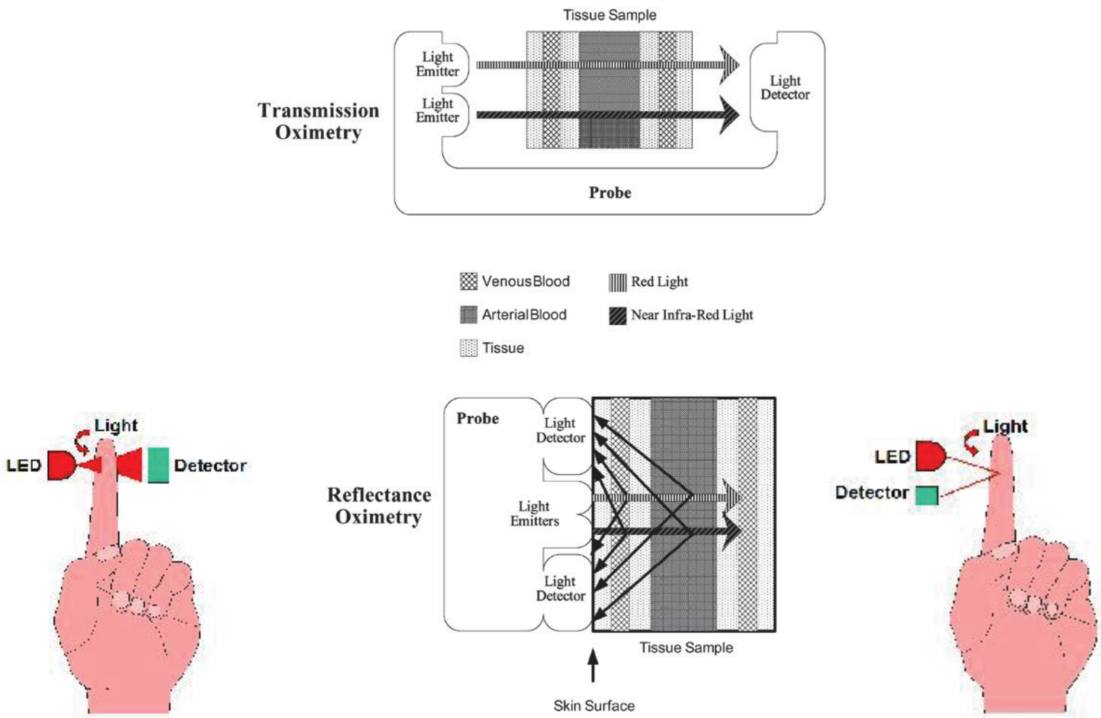

Fig 45: Transmition (left) and reflectance (right) methods

At the measuring site, there are constant light absorbers such as skin, venous blood and the arterial blood. However, with each heartbeat, the heart contracts and there is a surge of arterial blood which momentarily increases arterial blood volume across the measuring site. This results in more light absorption during the surge. If light signals received at the detector are plotted as a waveform, there should be peaks with each heartbeat and troughs between heartbeats. Conventional pulse oximetry accuracy has some constraints such as false or inaccurate measuring due to body motion. This makes medical decision making difficult. The advent of "Next Generation" pulse oximetry technology has demonstrated significant improvement in the ability to read through motion and low perfusion [53].

4.4.2. The design of the heart rate sensor

A heart rate monitor device is a tool that allows a person to measure his or her heart rate in real-time or record it for later study. This device uses a pair of infrared emitters and a receiver such as a phototransistor.

In the transmission method, the light emitted by the IR emitter passes through the measuring site and detected by the phototransistor. With each heartbeat, there is a surge which momentarily increases arterial blood volume across the measuring site. This results in more light absorption during the surge. If light signals received at the phototransistor are looked at 'as a waveform', there should be peaks with each heartbeat and troughs between heart beats. The infrared emitters and detectors from LITE-ON Electronics[1] are a pair of side-looking sensors. These devices operate at 940nm and work well for generic IR applications such as remote control and touch-less object sensing. The emitter is driven up to 50mA with a current limiting resistor as with any LED device. The detector is a NPN transistor that is biased by incoming IR lights. Fig. 46 shows the infrared emitter and phototransistor and a simple heart rate sensor schematic diagram which uses these types of sensors.

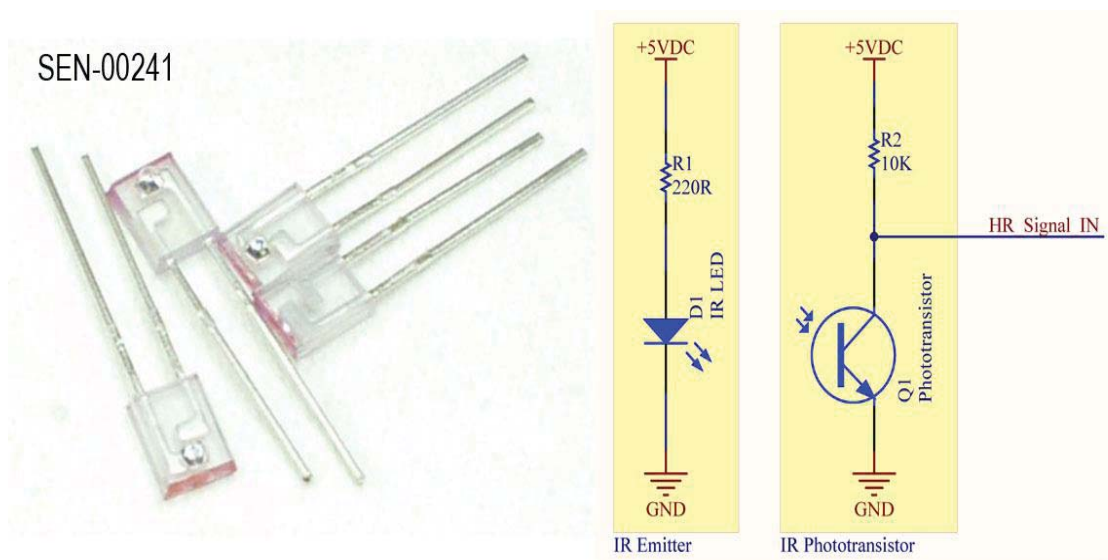

Fig 46: LITE-ON electronics IR emitter and detector - simple heart rate diagram

Since the signals to different people vary, some seem to have a very weak or even no signal. Therefore there is a need to amplify the signals detected by the phototransistor before any processing. This also amplifies any noises which can occur during the measurement and results in inaccurate reading. Therefore these signals are needed to be filtered.

[1] *Appendix I: SEN-00241 IR Photo-transistor and SEN-00241 IR LED datasheet*

4.4.3. Operational amplifiers

Operational amplifiers (OP-AMP's for short), are known as the workhorses of analogue circuitry. They can perform many tasks such as:

- Amplify the signals
- Comparing the two signals

The LM158[1] op-amps series consists of "two independent, high gains, internally frequency compensated operational amplifiers which were designed specifically to operate from a single power supply over a wide range of voltages" (LM358 Datasheet). According to LM358 datasheet, this op-amp:

- Has two internally compensated op amps
- Eliminates need for dual supplies
- Is compatible with all forms of logic
- Has power drain suitable for battery operation
- Is small in size and has normal DIP-8 pins and SMD version

In addition, this chip is very light in weight and cheap in price.

Weak signals coming out from the phototransistor are needed to be amplified in order to be useable. Since the LM358 families have two op-amps in one integrated circuit (IC), it is important to know how its pins are arranged. Fig. 47 shows the LM358 and its pins layout:

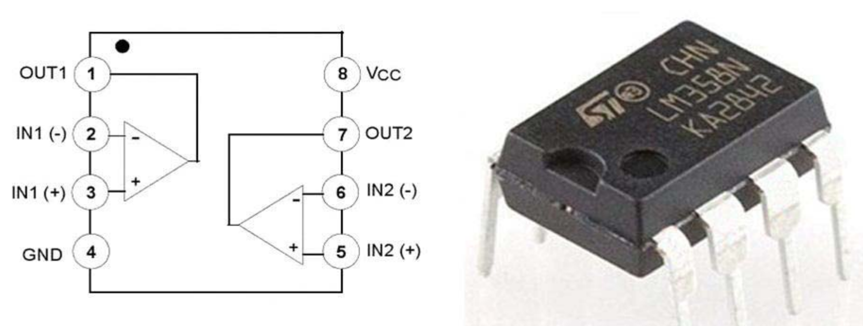

Fig 47: LM358 - pins layout

Op-amp's basic method of operation is to take the differences in the two incoming signals and amplify them. The "GAIN" is referring to how much the signal is amplified. It depends on the value of the resistors on the feedback loop. The feedback loop is the connection from the output and is fed back into the input of the op-amp (for example from pin 1 to pin 2). The LM358 Operational Amplifier is the main component of the trans-impedance amplifier to amplify a very small amount of current (micro-ampere) depending on the intensity of the IR light. As mentioned, the incoming signals from phototransistor might be noisy due to many factors (such as external frequencies) and need to be filtered.

[1] *Appendix I: LM358 dual op-amp datasheet*

4.4.4. Acquiring the signals

The signals acquired by the phototransistor go through a high-pass filter which filters all the frequencies below 0.67Hz. Because it is working on very low-frequency signals, this value is sufficient enough to minimize the low frequency noises.

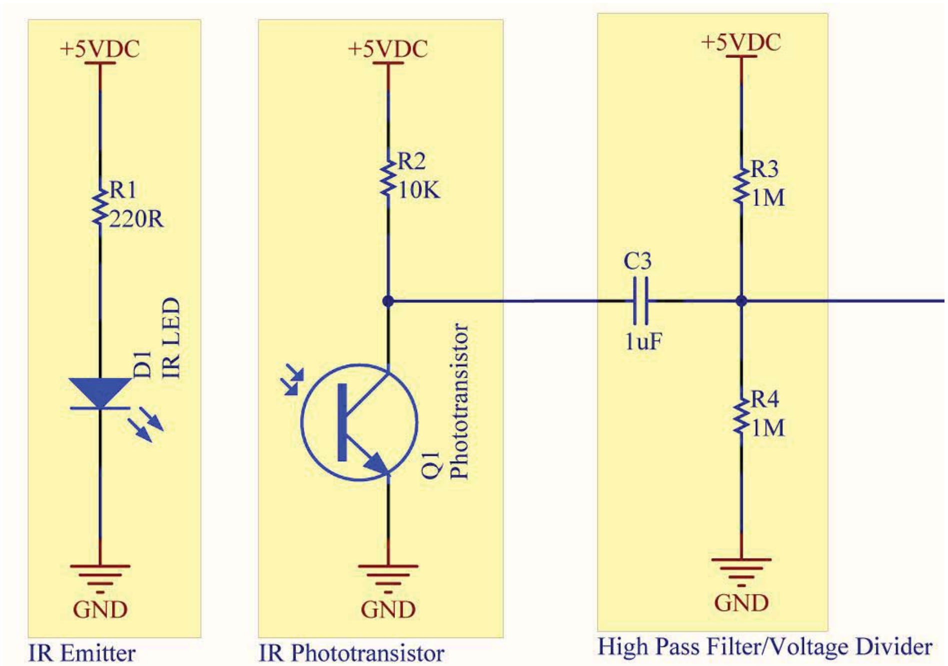

Fig 48: IR LED, phototransistor and high-pass filter

4.4.4.1. High-pass filter

The voltage output of the phototransistor is measured to be approximately 2.5V. It is indicated that phototransistor and resistor R_2 are acted as a voltage divider. On the other hand, according to RC circuit rule, the resistors R_3 and R_4 are in parallel. Therefore, the equivalent of resistors R_2, R_3, R_4 and R_p (phototransistor resistance) can be calculated as follow:

$$R_{2,3,4,p} = R_{2,p} + R_{3,4} = \frac{R_p * R_2}{R_p + R_2} + \frac{R_3 * R_4}{R_3 + R_4} = 5{,}000\Omega + 500{,}000\Omega = 505{,}000\Omega$$

$$f_{HighPassFilter} = \frac{1}{2\pi R_{2,3,4} C_3} = \frac{1}{2\pi * 505{,}000 * 470 * 10^{-9}} \approx 0.67 Hz$$

Equation 9: High-pass filter frequency

4.4.4.2. Voltage amplification

The output voltage of the high pass filter is about 200mV. It is required at least 2V (or above) to be able to have a clear signals which can be processed by the micro-controller. Therefore, the filtered signals are amplified with the Gain of 16. This gain will amplify the signals to reach approximately 3.2V: (16 * 0.2V = 3.2V)

$$R_{5,6} = \frac{R_5 * R_6}{R_5 + R_6} = \frac{100{,}000\Omega * 100{,}000\Omega}{100{,}000\Omega + 100{,}000\Omega} = 50{,}000\Omega$$

$$Gain = \frac{R_{12}}{R_{5,6}} + 1 = \frac{750{,}000\Omega}{50{,}000\Omega} + 1 = 15 + 1 \approx 16$$

Equation 10: Op-amp Gain

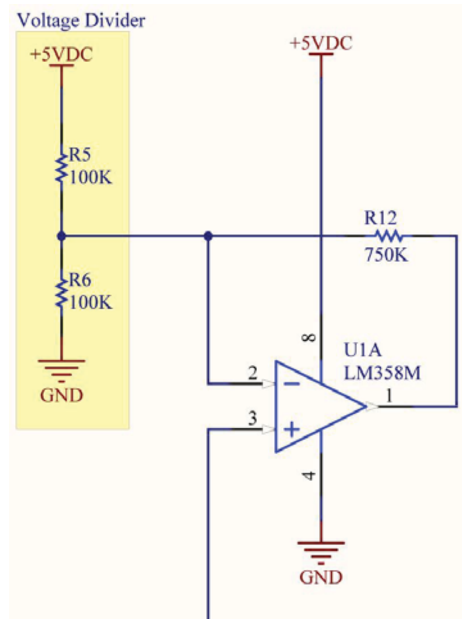

Fig 49: Voltage amplification

It is possible to set the gain up to 100 but the high gain of the op-amp causes the output to saturate at the highest positive or negative voltage it can output.

4.4.4.3. Low-pass filter

The amplified signal output from pin 1 of LM358 then passes through a low-pass filter with cut-off frequency of 6.03Hz. It will remove any frequencies above approximately 6Hz which are not very useful for measuring the heart rate. This frequency value is calculated by changing the values of the capacitor C_6 and resistor R_7 until the clear signals appears on the oscilloscope:

$$f_{LowPassFilter} = \frac{1}{2\pi R_7 C_6} = \frac{1}{2\pi * 120{,}000\Omega * 220 * 10^{-9} f} \approx 6.03Hz$$

Equation 11: Low-pass filter frequency

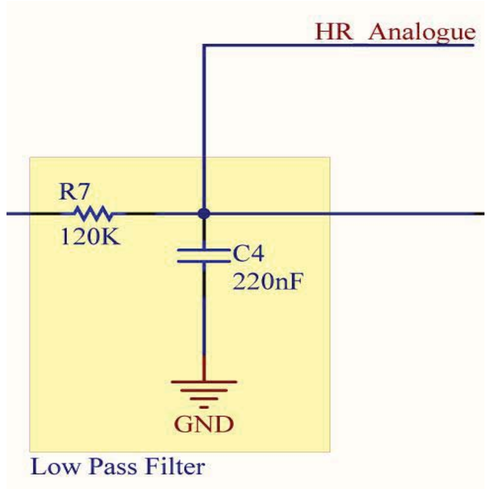

Fig 50: Low-pass filter

The output of the low-pass filter is then connected to analogue input of the micro-controller. The output signals of the first stage of the LM358, carry the information desired: the human heartbeat or pulse. These signals indicate the amplified voltage level detected by the phototransistor. Although it is possible to measure the heart rate from these signals, it would be easier to have digital output. This will reduce the amount of programming that is required to calculate the heartbeat from the signals. The comparator simply generates the high or low signals and then passes them to the micro-controller for further processing.

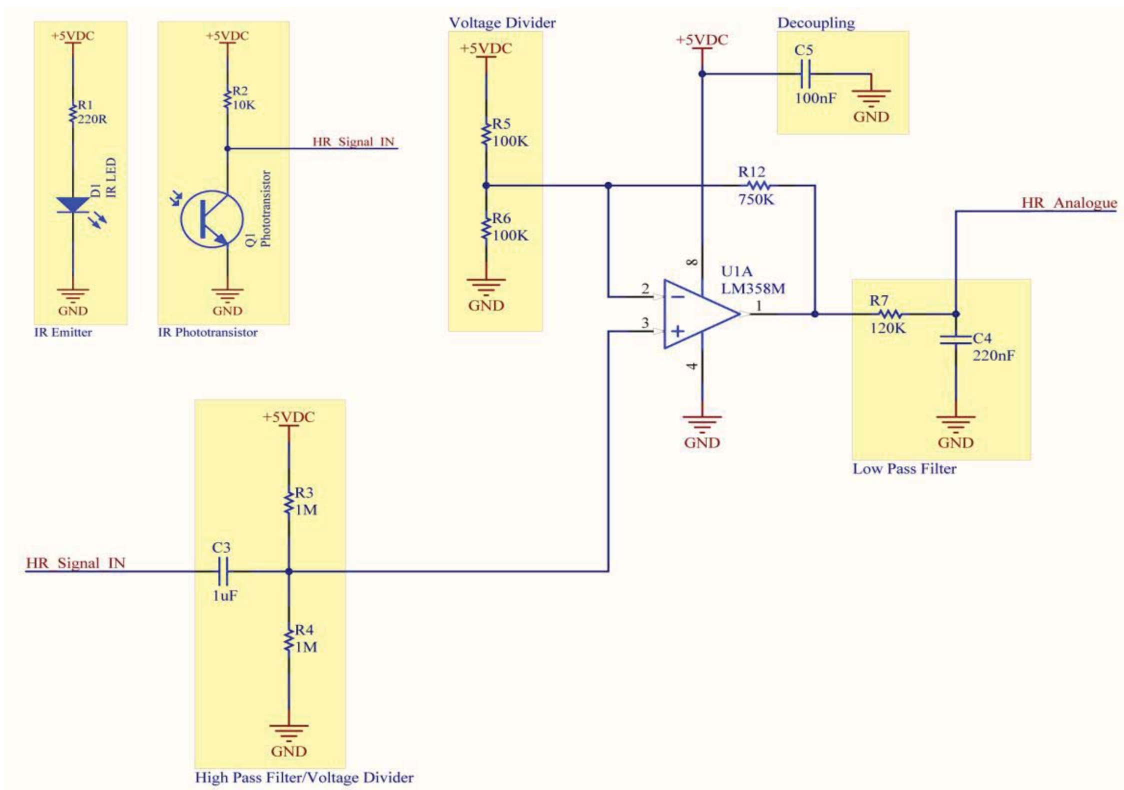

Fig 51: First stage of LM358 op-amp

4.4.5. The comparator

When an op-amp is operated as a comparator, the gain is then automatically set to maximum, also called “open-loop gain”. “The name open-loop gain comes from the absence of a loop or connection going from the output of the op-amp to either input of the same op-amp” (Wikipedia, retrieved 2011). The open-loop gain is varying depending on the op-amp model.[1] The LM358N has an open-loop voltage gain of 100. This means, when there is no connection between the output and either inputs of the op-amp they will automatically be amplified by factor of 100. However, no matter what the gain or input is, the output will still be limited by the voltage supply and cannot be larger than the supplied voltage.

ELECTRICAL CHARACTERISTICS (V_{CC} = 5.0 V, V_{EE} = Gnd, T_A = 25°C, unless otherwise noted.)

Characteristic	Symbol	LM258			LM358			LM2904			LM2904V			Unit
		Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	
Input Offset Voltage V_{CC} = 5.0 V to 30 V (26 V for LM2904, V), V_{IC} = 0 V to V_{CC} −1.7 V, V_O = 1.4 V, R_S = 0 Ω T_A = 25°C T_A = T_{high} (Note 1) T_A = T_{low} (Note 1)	V_{IO}	– – –	2.0 – –	5.0 7.0 2.0	– – –	2.0 – –	7.0 9.0 9.0	– – –	2.0 – –	7.0 10 10	– – –	– – –	– 13 10	mV
Average Temperature Coefficient of Input Offset Voltage T_A = T_{high} to T_{low} (Note 1)	$\Delta V_{IO}/\Delta T$	–	7.0	–	–	7.0	–	–	7.0	–	–	7.0	–	µV/°C
Input Offset Current T_A = T_{high} to T_{low} (Note 1) Input Bias Current T_A = T_{high} to T_{low} (Note 1)	I_{IO} I_{IB}	– – – –	3.0 – −45 −50	30 100 −150 −300	– – – –	5.0 – −45 −50	50 150 −250 −500	– – – –	5.0 45 −45 −50	50 200 −250 −500	– – – –	5.0 45 −45 −50	50 200 −250 −500	nA
Average Temperature Coefficient of Input Offset Current T_A = T_{high} to T_{low} (Note 1)	$\Delta I_{IO}/\Delta T$	–	10	–	–	10	–	–	10	–	–	10	–	pA/°C
Input Common Mode Voltage Range (Note 2), V_{CC} = 30 V (26 V for LM2904, V) V_{CC} = 30 V (26 V for LM2904, V), T_A = T_{high} to T_{low}	V_{ICR}	0 0	– –	28.3 28	0 0	– –	28.3 28	0 0	– –	24.3 24	0 0	– –	24.3 24	V
Differential Input Voltage Range	V_{IDR}	–	–	V_{CC}	–	–	V_{CC}	–	–	V_{CC}	–	–	V_{CC}	V
Large Signal Open Loop Voltage Gain R_L = 2.0 kΩ, V_{CC} = 15 V, For Large V_O Swing, T_A = T_{high} to T_{low} (Note 1)	A_{VOL}	50 25	100 –	– –	25 15	100 –	– –	25 15	100 –	– –	25 15	100 –	– –	V/mV

Fig 52: Electrical characteristics chart for LM358 op-amp[2]

Since the signals coming out of pin 7 of LM358 are transient signals, a flat (or DC signals) needs to be created so that the comparator has a reference point. The DC signal will be used as a threshold to tell the comparator op-amp when to turn on or off. When the signals levels are lower than the threshold, the comparator will turn off (0) and when they are higher than the threshold, the comparator will turn on (1). Fig. 53 shows the adjustable DC threshold level and a sample heart rate signals:

[1] *The open-loop gain information is usually found on the datasheet of the specific op-amp being used*

[2] *Reference: electrical characteristics chart for LM358 op-amp*

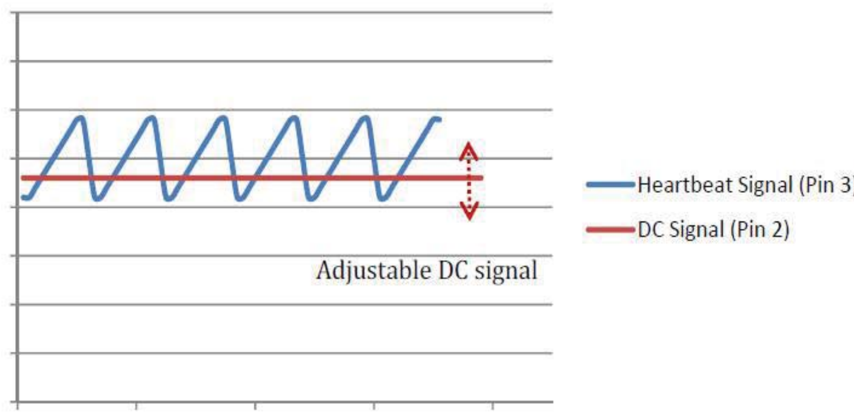

Fig 53: Simulation of signals entering the comparator of op-amp

The reference and input voltages can be anywhere between zero and the supply voltage. But there are practical limitations on the actual range depending on the particular device being used. Fig. 54 shows two different ways of using a comparator:

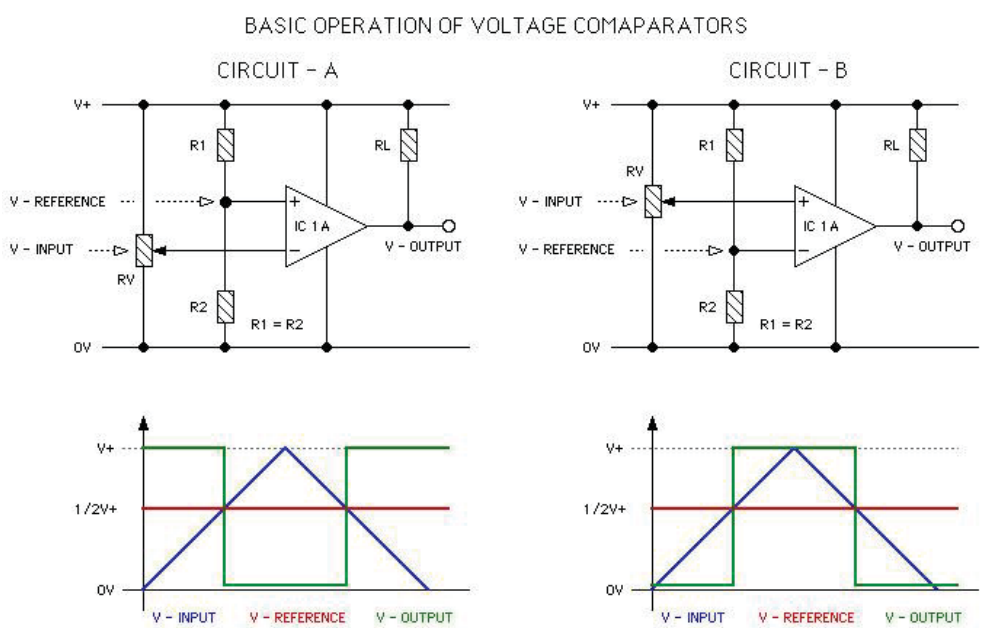

Fig 54: Basic comparator operation

Fig. 55 shows that if the voltage at the positive input is lower than the voltage at the negative input, the current will flow through the open collector. On the other hand, if the voltage at the positive input is higher than the voltage at the negative input, the current will not flow through the open collector.

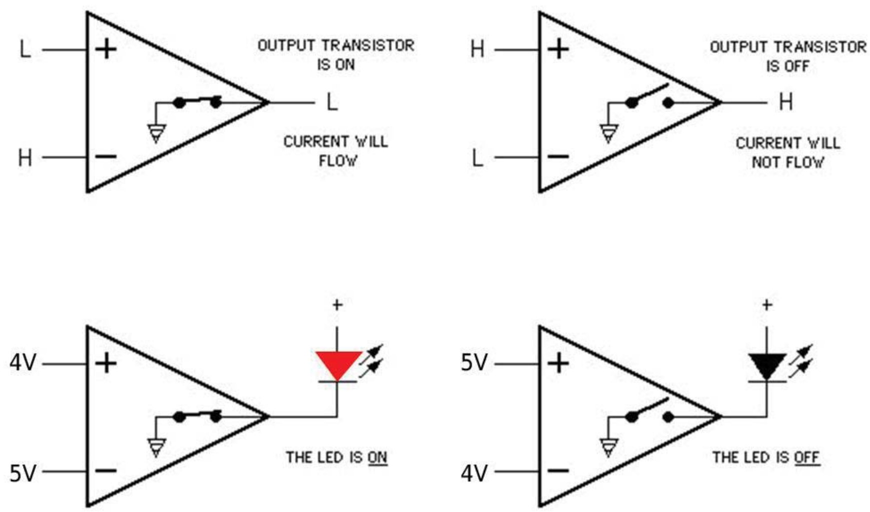

Fig 55: Comparator - input vs output rules

Therefore, the second stage of LM358 is used as a comparator. A $10K\Omega$ potentiometer is used to create the adjustable voltage reference to the LM358 comparator (positive input pin 5). The incoming signal (voltage) from pin 1 goes to pin 6 and is compared with the supplied voltage reference.

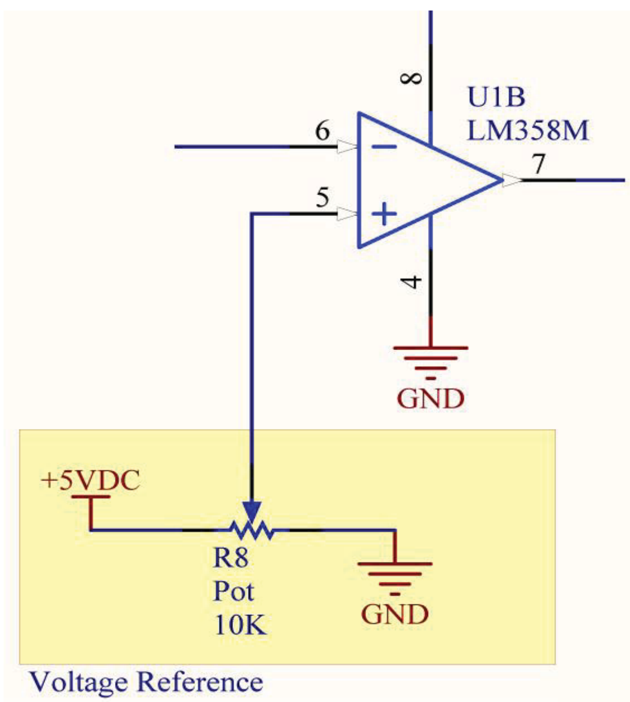

Fig 56: Comparator and voltage reference

The result of the comparison between input voltage (pin 6) and threshold level (pin 5) is used to drive a LED indicating the heartbeats.

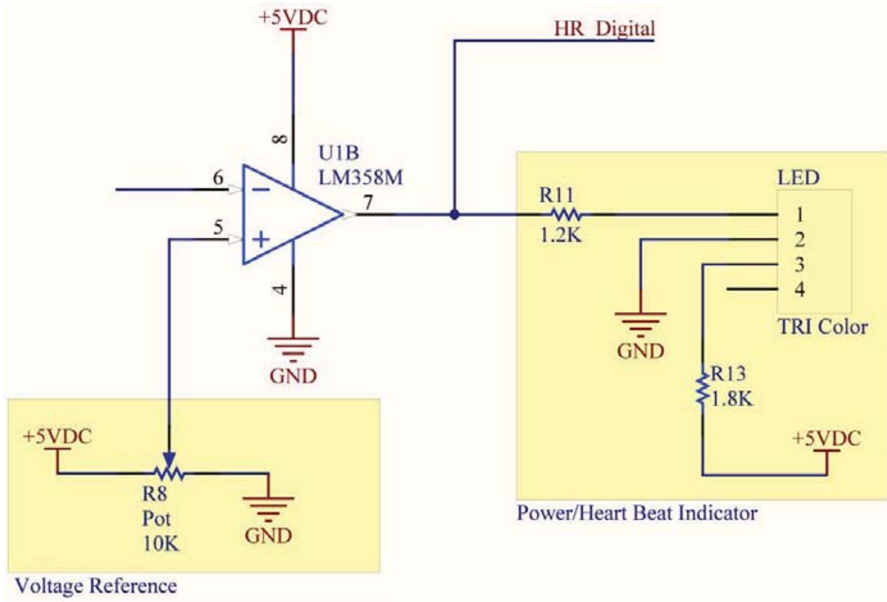

Fig 57: Comparator and a TRI-colour LED[1]

The output of pin 7 is used to measure the heartbeats. It is connected to the digital input of the Arduino micro-controller. The number of 1's (high) generated by the comparator is counted over some period of time in order to calculate the heartbeats. For example, if the number of 1's over 10 seconds is equal to 12, then the heartbeat will be 6 * 12 = 72 beats per minutes.

A TRI-Color is used for indications of power and heartbeats. The red color is used for the system power status and the green color for indicating the heartbeats. TRI-Color LEDs have the following features[2].

- Forward Voltage (RGB): 2.0, 3.2 and 3.2 V
- Max Forward Current (RGB): 20, 20 and 20 mA
- Max Luminosity (RGB): 2800, 6500 and 1200 mcd

They have the high luminosity values for red, green and blue colors. They become very bright even with a low current. Therefore, in order to save power and draw less current, the value of the resistors on the TRI-Colour LED is chosen to be large.

A resistor must connect to a LED in series to limit the current through it. Otherwise, it will burn out almost instantly. The resistor value R for an LED can be determined by simple OHMs law.

[1] TRI-Color LED is a 5mm unit that has four pins. Three pins, one for each color and a common cathode. Is used as a two status indicator: one for power (red) and one for heartbeat (green)

[2] Appendix I: TRI-Color LED

$$R = \frac{V_S - V_L}{I}$$

Equation 12: LED resistor value

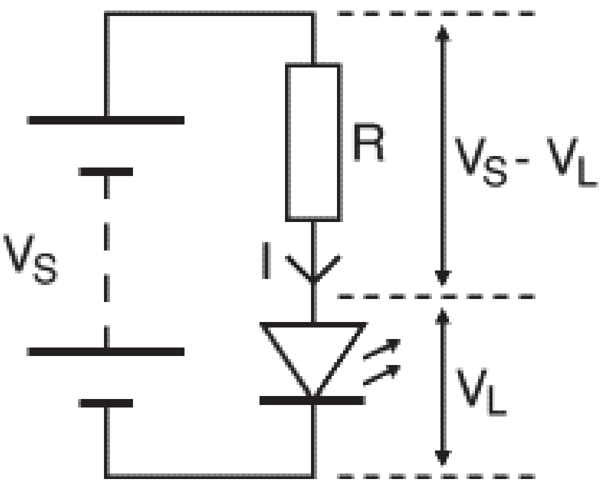

Fig 58: Calculating the resistor value for LED

Where: V_S = Supply voltage, V_L = LED voltage and I = LED current

The LED current must be less than the maximum current permitted. It current must be converted to amps (A) so the calculation will give the resistor value in ohms (Ω). If the calculated value is not available, for example $40K\Omega$, the nearest standard resistor value which is greater can be choose. If the supply voltage is $V_S = 5volts$, the LED voltage is $V_L = 2volts$ and require current is $I = 20mA = 0.020A$, therefore, the value of the resistor will be:

$$R = \frac{V_S - V_L}{I} = \frac{5-2}{0.02} = 150\Omega$$

In fact, it may be possible to choose a greater resistor value to reduce the current drawn by the sensor. It will make the LED less bright but reduce the current and increase the battery life. Therefore, a super-bright LED with 9000 MCD[1] luminous intensity is chosen with the resistor values of $1.2K\Omega$ for blinking LED's and $1.8K\Omega$ for power LEDs that is intended to stay on at all times.

[1] *MCD stand for "mill-candela" or 1/1000 of a candela. This is the unit of light energy of a single color, single direction.*

4.4.5.1. Input offset voltage

Voltage comparators are not perfect devices and their performance may suffer from the effects of a parameter known as the Input Offset Voltage (IOV[1]). "The IOV can range from microvolts to milli-volts. Generally, bipolar op amps have lower offset voltages than JFET or CMOS types"[2]. Problems related to the input voltage normally occur when it changes very slowly. The net result of the IOV is that the output transistor does not fully turn on or off when the input voltage is close to the reference voltage. Fig. 59 illustrates the effect of the IOV with the slow changes on the input voltage. This effect increases as the output transistor current increases. Therefore, keeping the value of RL high will help to reduce the problem.

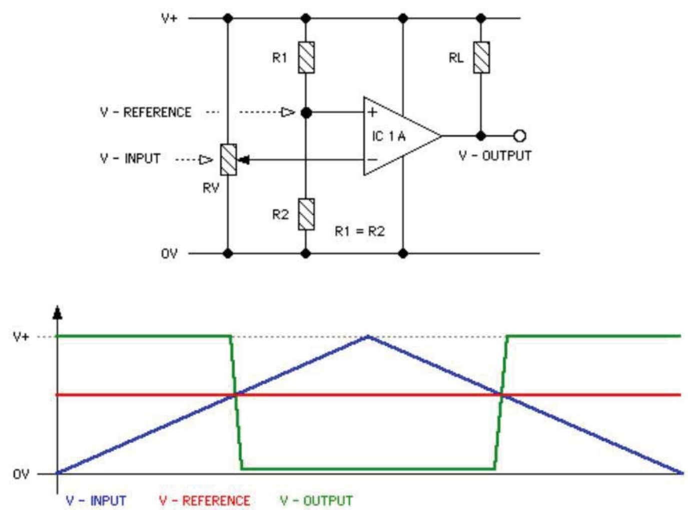

Fig 59: Effect of input offset voltage on the output voltage

Temperature has an effect on input offset voltage. "The input offset voltage will change ΔV (voltage drift) with a change in temperature ΔT"[2]. Therefore, the error that is a linear function of temperature is defined as:

$$V_{err} = \Delta V * \Delta T$$

Equation 13: Linear function of temperature voltage error

For example, for a $\Delta V = 25\mu V/^{\circ}C$ and $\Delta T = 10^{\circ}C$, the drift over will be:

$$V_{err} = (25\mu V/^{\circ}C)*(10^{\circ}C) = 0.25mV$$

[1] *Input offset voltage is the differential DC voltage required between the inputs of an amplifier, especially an operational amplifier, to make the output zero (0 volts with respect to ground, or between differential outputs if they exist, for voltage amplifiers*

[2] *OP-Amp Input Offset Voltage. From, www.ecircuitcenter.com/Circuits/op_voff/op_voff.htm: Retrieved Aug 2011*

By knowing the overall error budget, it is possible to select an op amp with a low enough offset drift to meet the target circuit performance.

4.4.5.2. Input offset voltage and hysteresis

For most comparator circuits, hysteresis is the difference between the input signal voltages at which a comparator's output is either fully ON or fully OFF. Small voltage fluctuations due to noises, which always present at the inputs, can cause undesirable rapid changes between the two output states when the input voltage difference is near zero volts. To prevent this output oscillation, a small hysteresis of a few milli-volts can be added to the circuit. It reduces the sensitivity to noise or a slowly moving input signal.
Internal hysteresis that is normal for comparators causes the output of the comparator to go from OFF to ON and vice-versa relatively slowly. External hysteresis uses positive feedback from the output to the non-inverting input of the comparator. The effect of adding hysteresis is that as the input voltage slowly changes, the reference voltage will quickly change in the opposite direction. This gives the comparator's output a "snap" action.

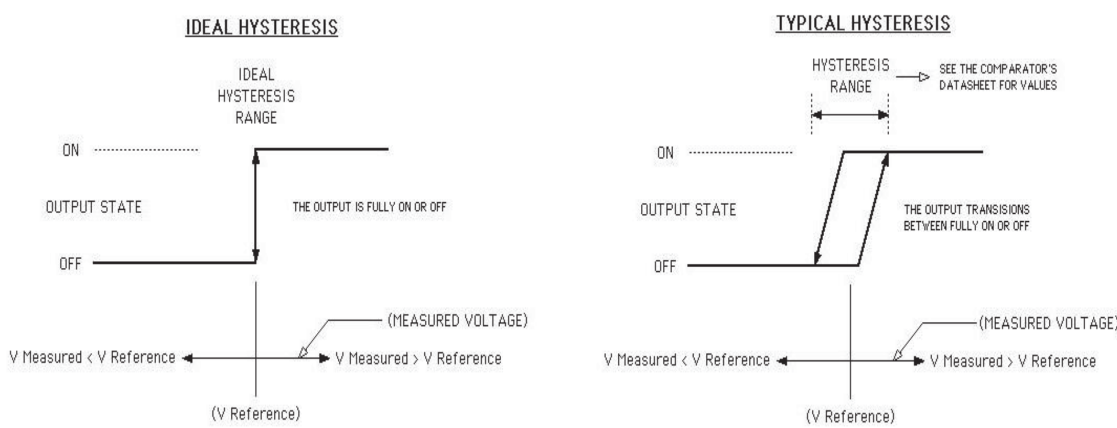

Fig 60: Ideal (right) and typical (left) comparator hysteresis

In an ideal comparator, the hysteresis voltage range would be zero volts and the output fully ON or OFF while in a typical comparator, the hysteresis voltage range may be a few milli-volts and the output has a range which is between fully ON or OFF.

3.7.2.6. Adding hysteresis to a comparator circuit

A comparator's Hysteresis range can be increased by adding a resistor between the comparator's output and the positive input terminal. This creates a feedback loop so that when the output makes a transition the feedback changes the voltage at the positive which increases the voltage difference between the positive and negative inputs. The feedback can only be made to the positive input terminal.

If the comparator's output is initially 'OFF', the negative input voltage has to become above the positive input voltage by the hysteresis voltage range before the comparator output turns 'ON'. If the comparator is 'ON', the negative input voltage needs to drop slightly below the positive input voltage by the hysteresis voltage range before it turns 'OFF'. The hysteresis voltage range can also be made quite large in order to force the comparator's output to change as quickly as possible. To add a hysteresis to the LM358 comparator, resistors $R_{10} = 390K\Omega$ and $R_9 = 10K\Omega$ are connected to the comparator. The value of the hysteresis is then calculated as:

$$Hysteresis = \frac{390{,}000\Omega}{10{,}000\Omega} = 39$$

Equation 14: Op-amp comparator hysteresis

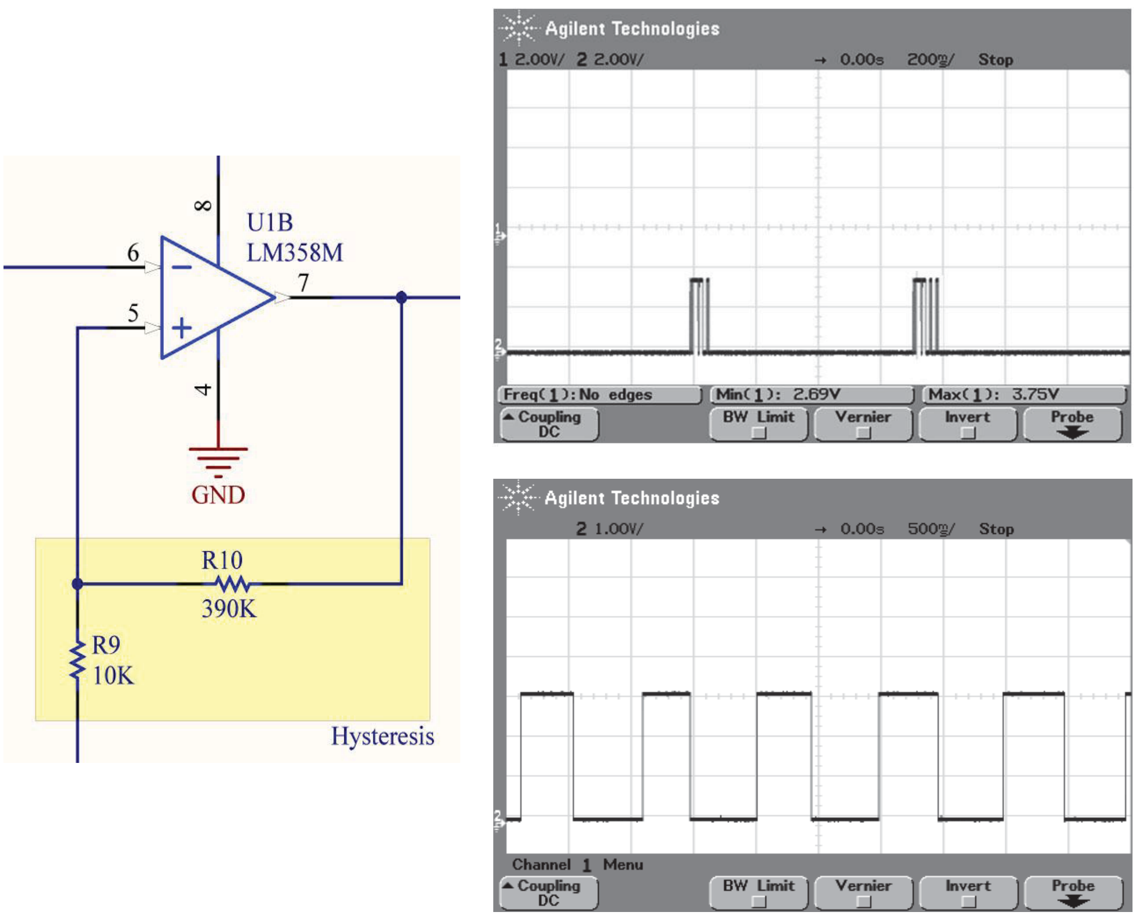

Fig 61: Adding hysteresis to LM358 comparator and the effect on digital outputs

4.4.6. Heart rate sensor testing

Almost all electronics projects start the life from a breadboard to make sure the circuits work as intended. Therefore, a breadboard is used to make-up temporary circuits for testing. Because no soldering is required on the breadboard, it is easy to change connections and replace the components. In addition, the parts will not be damaged so they will be available to be re-used afterwards. Fig. 62 shows the breadboard design of the heart rate sensor and Fig. 63 shows sample analogue and digital outputs on the oscilloscope. The analogue and digital outputs of the sensor are connected to the Arduino micro-controller:

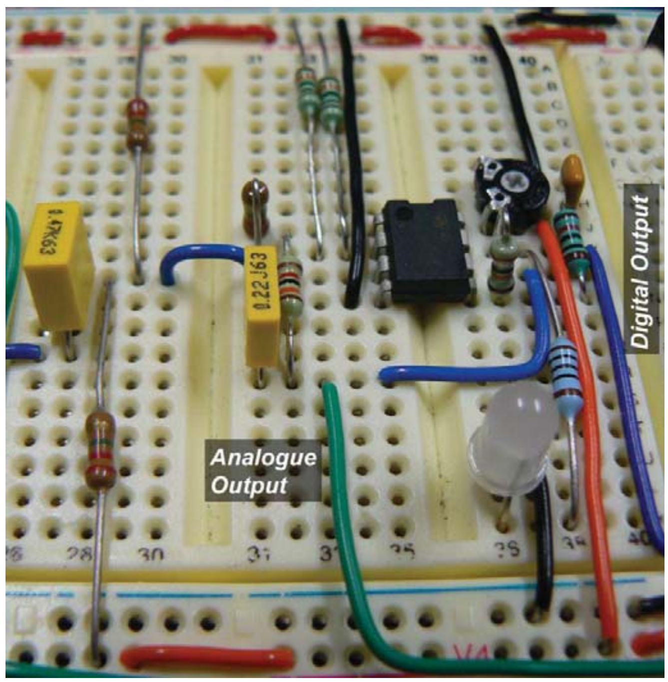

Fig 62: Heart rate sensor on breadboard

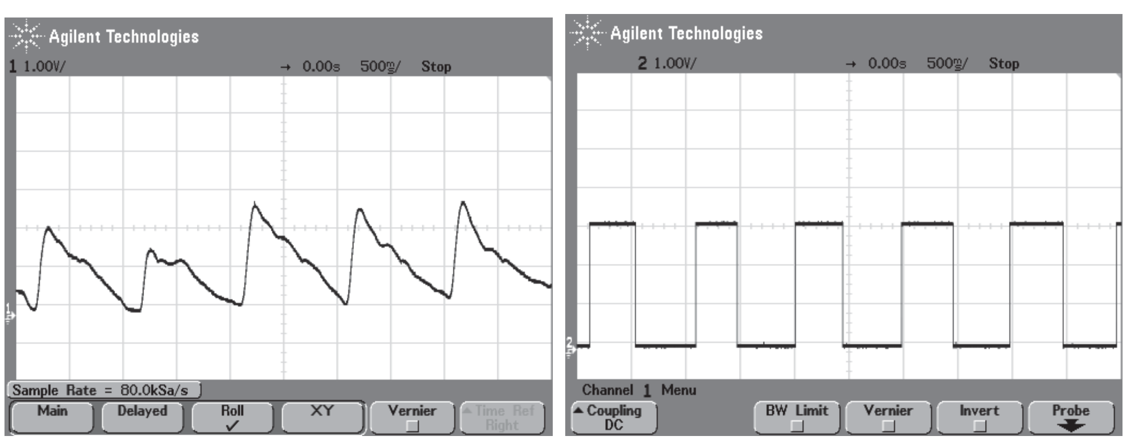

Fig 63: Analogue (left) and digital (right) outputs

4.5. Liquid crystal display

In order to display the results of the readings from the sensors, a Liquid crystal display (LCD) is added to the design. LCDs come in different shapes, colours and sizes. One of the the most common types is a 16*2 (16 characters by two lines). Arduino micro-controller uses the LiquidCrystal library[1] to communicate with the LCD display. Fig. 64 shows the layout of a 16*2 LCD display:

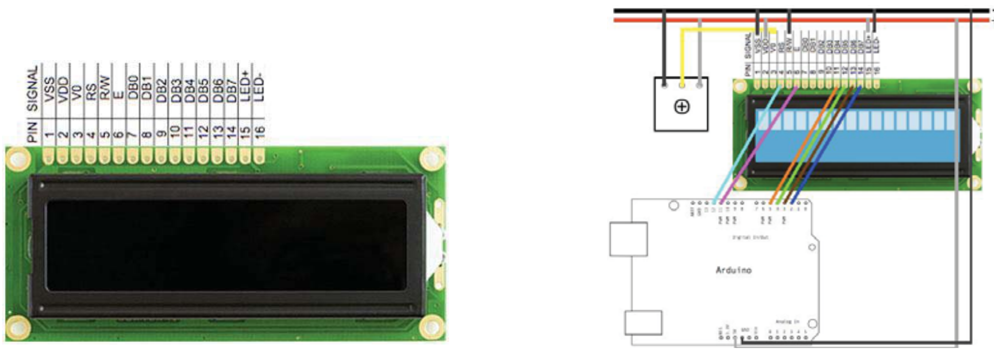

Fig 64: 16*2 characters LCD display and its connection to Arduino

ElectroLite LCD display[2] has 16 connection pins. The first fourteen pins are used to control the display and the last two are reserved for the backlighting. It is not necessary to use all the pins to communicate with the Arduino micro-controller. Fig. 65 shows the required wiring in order to connect a 16*2 LCD display to the Arduino to display a text. A 10kΩ potentiometer is used to control the brightness of the characters on the screen. The LCD power is obtained from the 5V output of the Arduino micro-controller.

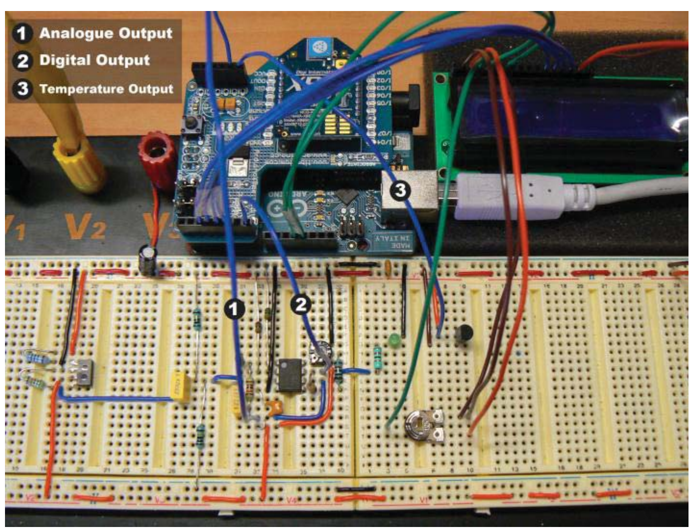

Fig 65: Connecting the LCD display to Arduino micro-controller

[1] Reference: arduino.cc/en/Reference/LiquidCrystal

[2] Appendix I: LITEON LCD display datasheet

4.6. Standalone Arduino

The Arduino micro-controller is suitable for quick prototyping. It uses ATmega micro-controller chip families. This chip can be used by itself in a breadboard or a prototyping board in order to make the prototype smaller, cheaper and lighter. The cost of having a pre-built Arduino board can be minimized by designing a circuit board based on the ATmega chip. The circuit board can be made by adding just the bare bones circuitry needed to support the ATmega chip.

4.6.1. ATmega328 chip[1]

The high-performance Atmel Pico Power 8-bit AVR is a RISC-based micro-controller. It combines a 16KB ISP flash memory with read/write capabilities. According to its characteristics, it has:

- 512Byte EEPROM with 1KB Static Ram (SRAM - maximum of 4KB in 328 families)
- 23 general-purpose I/O lines and 32 general purpose working registers
- Three flexible timer/counters with compare modes
- Internal and external interrupts
- A byte-oriented 2-wire serial interface
- A 6-channel 10-Bit Analogue/Digital Converter (ADC)
- Five selectable power saving modes

The device requires 2.7-5.5V to operate. Fig. 66 shows the ATmega168/328 pins layout:

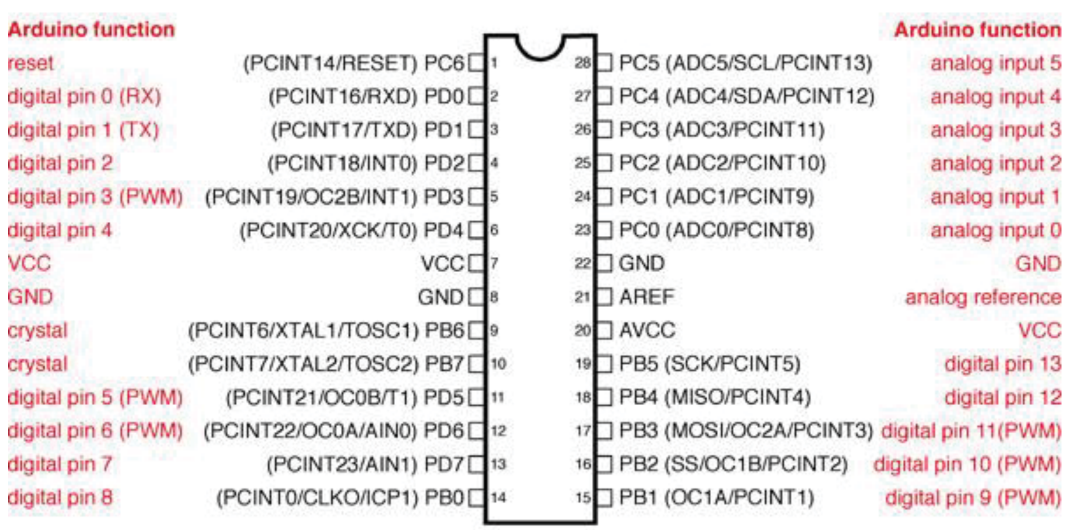

Fig 66: ATmega328 pins layout[2]

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[1] *Appendix I: Atmel/ATmega chip datasheet*

[2] *Reference: sustburbia.blogspot.com*

Based on the above characteristics of the ATmega chip, the following steps need to be taken in order to make a standalone Arduino:

- Connects a 10KΩ pull-up resistor to +5V from the RESET pin (pin 1 of the ATmega328) in order to prevent the chip from resetting itself during normal operation. The RESET pin reboots the chip when pulled down to the ground. It connects to a push button to enable the user to reset the chip whenever it is required.
- Connect Pin 7 (Vcc) to +5V, Pin 8 and Pin 22 to GND, Pin 21 to a +5V to supply analogue reference for ADC and Pin 20 to AVcc to supply voltage for the ADC.
- The ATmega328P-PU runs at 16MHz clock speed. Therefore, it is required to add a 16MHz external oscillator (crystal or resonator) between pin 9 and 10 with two 22pF or 18pF capacitors running to ground from each of those pins. The capacitors external to the crystal are contained within the feedback loop of the oscillator circuit. For "parallel" resonant crystals, the value of load capacitance needs to be specified by the manufacturer to ensure initial frequency tolerance. Parallel resonant crystals are intended for circuits, which contain reactive components (capacitors) in the oscillator feedback loop. These circuits depend on the reactive components and the crystal to achieve the phase shift needed to start and maintain oscillation at a specified frequency. Fig. 67 shows a parallel resonant crystal[1] and Fig. 68 shows the micro-controller pins required to be connected to the crystal:

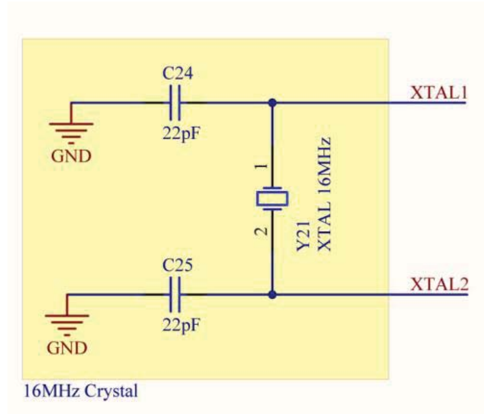


Fig 67: Parallel resonant crystal

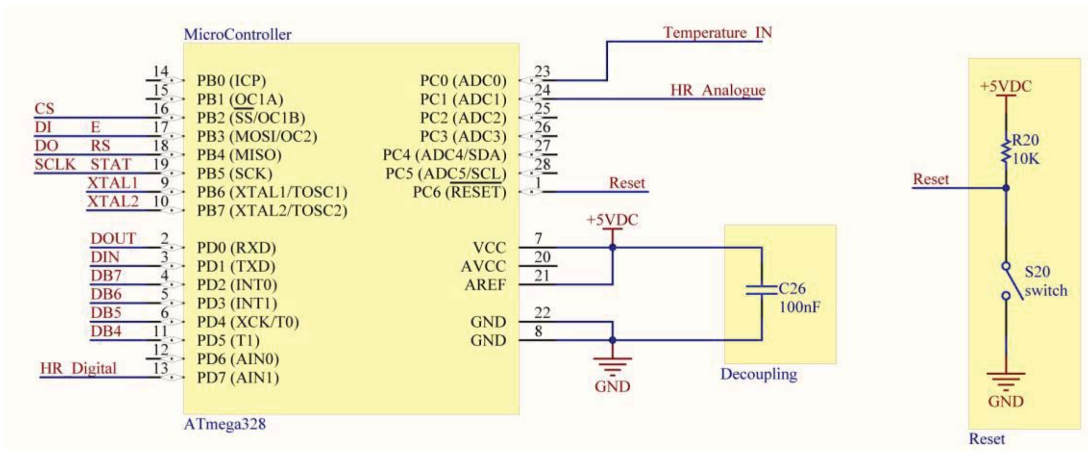


Fig 68: ATmega328 connections schematic

[1] *Appendix I: ATmel/ATmega chip datasheet - best capacitor value for ATmega328 micro-controller chip*

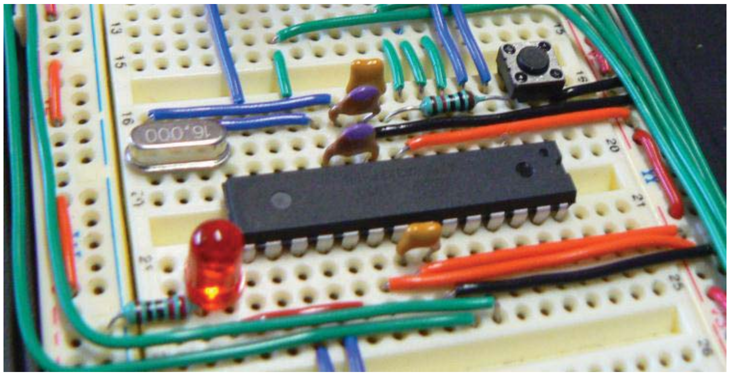


Fig 69: Standalone ATmega328 chip on breadboard

4.6.2. Voltage regulator

The ATmega328 operates within a range of 2.7 to 5.5V. The LM2940CT-5[1] is a common low-dropout (LDO) linear regulator. The regulator's dropout voltage is the voltage required between the input and the regulated output voltage. This voltage multiplied by the current ($Q = V * I$) is wasted by the regulator (turned into heat). So the lower the dropout on a linear regulator, the more efficient the regulator is. This means that the regulator stays much cooler than a standard LM7805 that would require a much higher input voltage (around 7.5 volts) for a regulated 5V output. The following steps need to be taken in order to make a voltage regulator:

- The input from the external power supply connects to pin1 (in), ground is in the middle (GND). Pin 3 (OUT) is a fixed 5V output.
- A 0.47uF capacitor needs to be added between the IN and GND and a 33uF capacitor between the OUT and GND (The LM2940CT-5 datasheet suggested to use a 0.47uf capacitor on the input and 22uF on output). The output capacitor must be at least 22uF to maintain stability. It may be increased without limits to maintain regulation during transients. It must be located as close as possible to the regulator. This capacitor must be rated over the same operating temperature range as the regulator. Fig. 70 shows a simple connection of the LM2940CT-5 voltage regulator according to its datasheet:

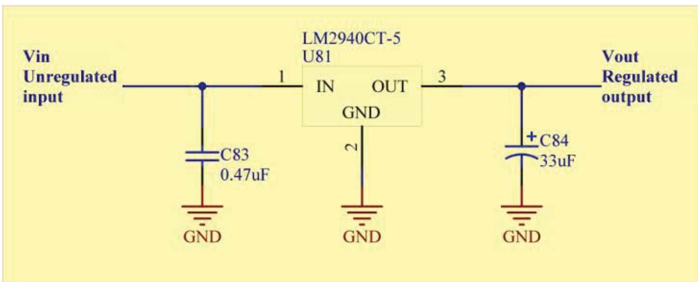


Fig 70: LM2940CT-5 typical application

[1] Appendix I: LM2940 voltage regulator datasheet

- Adding an optional LED and a resistor (for example 120Ω). An LED attached to power like this is a great troubleshooting trick. It indicates whether the board is being powered or shorted
- The LM2940CT-5 operates within 7-16V supply. Any lower voltage will not get 5V out of the regulator. Any higher and the regulator may be damaged the regulator
- A 1N4148 diode is connected to the input in order to protect the regulator being damaged by the changes in the input voltage. It is used just after the input voltage and before the other capacitors because most of the capacitors are polarized.

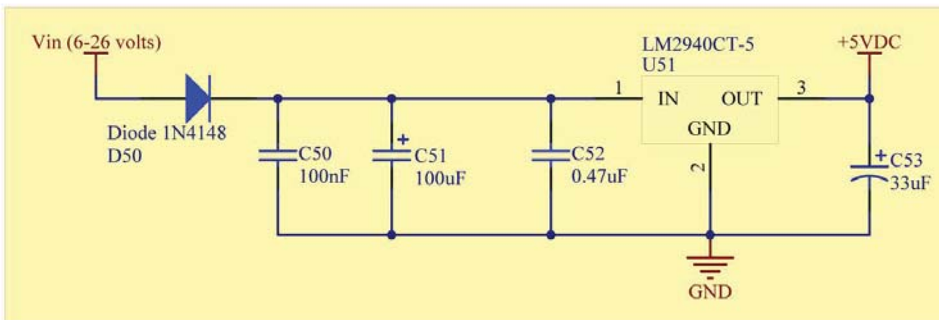


Fig 71: LM2940CT fixed 5V voltage regulator complete schematic

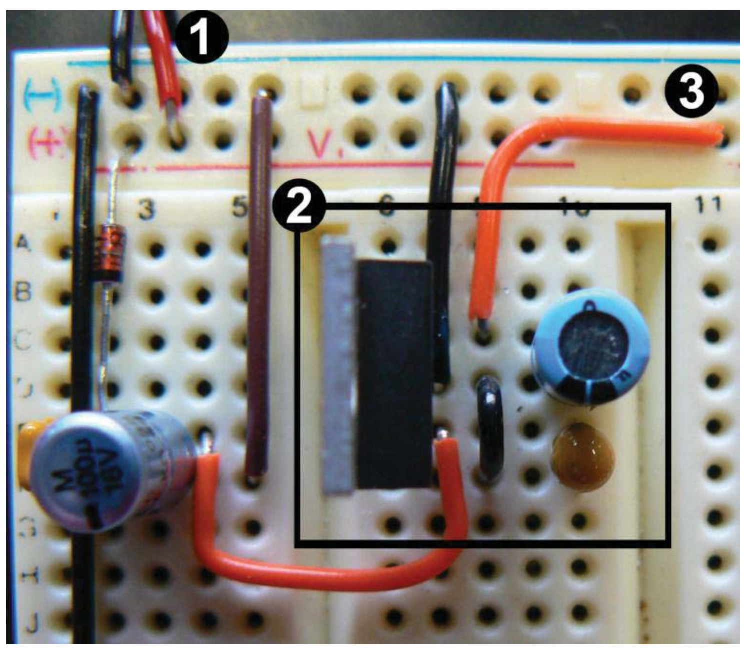


Fig 72: LM2940 5V voltage regulator 1- input, 2- regulator, 3-fixed 5V output

4.7. Logging data

Data logging can be used in remote situations. It enables the device to be able to store the data captured by the sensor. This feature allows the device to save the data in both on-line and off-line communication mode. It is an important capability to record the data in case of communication failures such as XBee module stops working or the receiver is down. It also adds the capability to have a complete history of logged data which can be read separately without the actual device being presented.

4.7.1. Memory cards

Secure Digital card (SD card) is a non-volatile[1] memory format developed by the SD Card Association[2] (SDA) for use in portable devices. The SD card families are divided into the:

- SD Standard Capacity (SDSC), commonly termed SD, has an official maximum capacity of up to 4GB
- SD High Capacity (SDHC) with a capacity between 4GB to 32GB
- SD eXtended Capacity (SDXC) with the capacity above 32 GB with a maximum of 2TB

Each SD card family is available in up to three physical sizes. The SD and SDHC families are available in all three sizes, but the SDXC family is not available in the mini size:

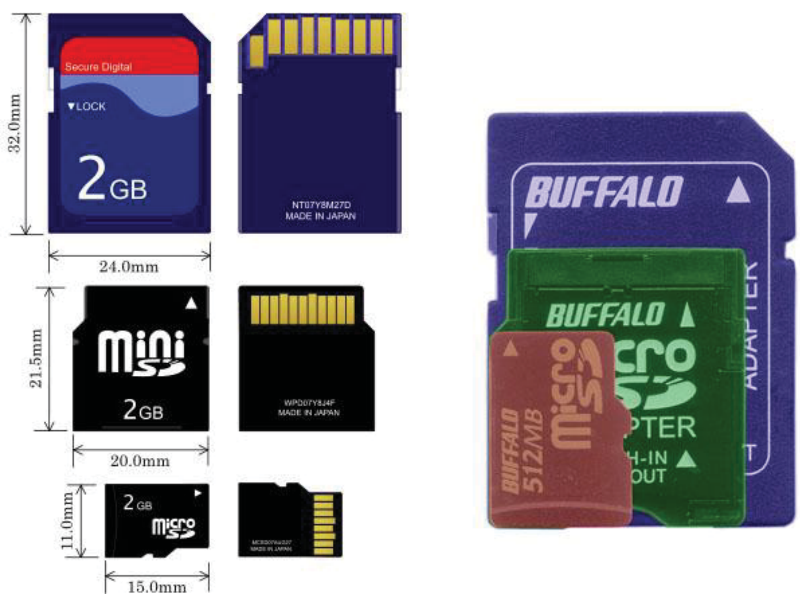


Fig 73: SD (top), Mini-SD (middle), Micro-SD (bottom)[3]

[1] Non-volatile memories are the types of memory that retain their contents when power is turned off

[2] Reference: en.wikipedia.org/wiki/SD_Card_Association

[3] Reference: Wikipedia

4.7.2. File System

File Allocation Table (FAT) is a computer file system architecture, widely used on many computer systems and most memories such as hard disks, RAMs and memory cards. The name originates from the usage of a table which centralizes the information about which areas belong to files, are free or possibly unusable, and where each file is stored on the disk. The successive major versions of the FAT format are named after the number of table element bits: 12 (FAT12), 16 (FAT16), and 32 (FAT32). The extended file allocation table (exFAT), developed by Microsoft is a proprietary file system, designed especially for USB flash drives and memory cards which can be supported by Windows operating systems. SDSCs are typically formatted as FAT16, SDHCs as FAT32, SDXCs as exFAT. The ubiquity of FAT16 and FAT32 allows those cards to be accessed on virtually any host device with an SD reader. In addition, standard FAT maintenance utilities (e.g., SCANDISK) can be used to repair or retrieve corrupted data and some utilities can recover deleted files. However, the card appears as a removable hard drive to the host system and can be re-formatted to any file system supported by the operating system. SD cards with 4GB and smaller capacities can be used with many systems by being formatted with FAT16 (4GB only possible by using 64KB clusters, and not widely supported) or FAT32 file system (common for file systems 4GB and bigger). Cards with the 4GB capacity or larger can only be formatted with a file system that can handle these storage sizes, such as FAT32 or exFAT.

4.7.3. Transfer mode

Depending upon the ability of a specific SD card, it may support various combinations of the following bus types and transfer modes (the SPI bus and one-bit SD bus are mandatory for all SD families)[1]:

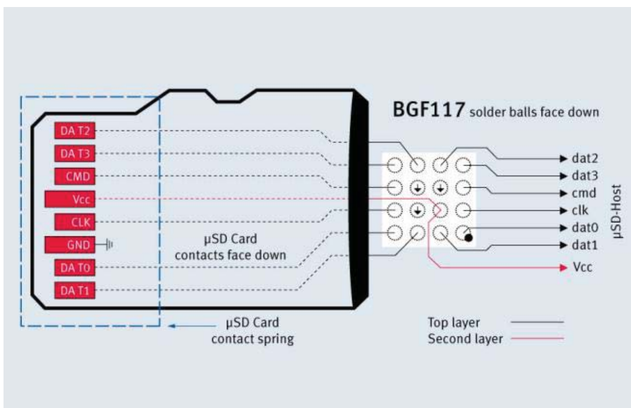
- SPI: Serial Peripheral Interface bus is primarily used by embedded micro-controller s. This bus type supports only 3.3V power and communications
- One-bit SD: Separates command and data channels and a proprietary transfer format
- Four-bit SD: Uses extra pins plus some re-assigned pins

All SD card families must be able to run at 3.3V with a 3.3V logic electrical interface. The signaling buses support various clock rates, including a stopped clock. After power-up, the host must communicate with the SD card up to a maximum clock rate called the Default Speed (DS), which is a bus clock up 50MHz and at a high-speed. The power consumption of micro-SD cards varies by manufacturer, but appears to be in the range of 66-330mW (20-100mA at a supply voltage of 3.3V).

[1] *Appendix I: Micro-SD card datasheet*

4.7.4. Micro-SD card and bus modes

The Micro-SD cards are highly integrated flash memories with serial and random access capability. They are accessible via a dedicated serial interface optimized for fast and reliable data transmission. It has been developed to provide an inexpensive, mechanically robust storage medium (in a card form) for multimedia consumer applications. Micro-SD card allows the design of inexpensive players and drivers without moving parts. Low power consumption and a wide supply voltage range favors mobile, audio players, organizers, electronic books, encyclopedia and dictionaries. Using very effective data compression schemes such as MPEG, the Micro-SD card will deliver enough capacity for almost all kinds of multimedia data.



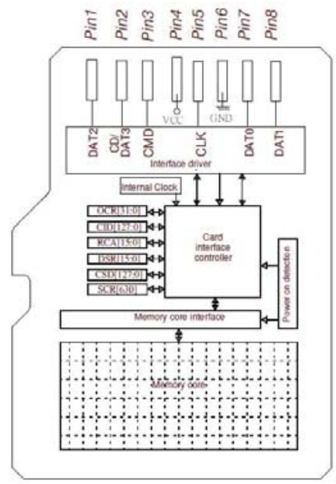


Fig 74: Micro-SD card PCB layout (left) block diagram (right)

The Micro-SD card has on card error correction and supports two SD and SPI mode communication protocols. It has a variable clock rate from 0 to 25MHz and requires 2.7 to 3.6V power supply to operate. It also has a high-speed serial interface with random access, a cost-effective solution with ultra-high performance of flash access time with a high reliability of data, low power consumption with automatic power down/automatic wake up and smart power management. The SD bus allows the dynamic configuration of the number of data lines from one to four bi-directional data signal. After powering up, the Micro-SD card will use only DAT0. After finishing the initializations, the host can change the bus width. Common VCC, Vss, and CLK signal connections are available in the multiple connections. However, Command, respond and data line (DAT0~DAT3) must be divided for each card from the host[1]. This feature allows easy trade-off between hardware cost and system performance. Communication over the SD bus is based on command and data bit stream initiated by a start bit and terminated by stop bit. With each cycle of this signal, a single bit transfer on the command and data lines is performed. The frequency may vary between zero and the maximum clock frequency. The Micro-SD card

[1] *Appendix I: Micro-SD card datasheet*

bus master is free to generate these cycles without restriction in the range from 0 to 25MHz (at low speed) and up to 50MHz (at high speed). Commands are transferred serially on the command line. A command is a token to start an operation from host to the card. “Commands sent to the address single card (address command) or to all connected cards (broadcast command). Responses are transferred serially on the CMD line. A response is a token to answer to a previous command. Responses sent from a single card or from all connected cards”.

SPI is a one-bit data line with 2-chanels (Data In and Out). The SPI mode allows the multimedia controllers (MMC) to use the Micro-SD card with little change. All the data tokens are multiples of the bytes and always byte aligned to the CS signal. The advantage of the SPI mode is reducing the effort in designing the host. Especially, the MMC host can be modified with little change. The disadvantage of the SPI mode is the loss of performance versus SD card mode.

4.7.5. Adding memory card to the system

An extended memory card enables the device to store the data captured by the sensor. This feature allows the device to save the data in both on-line and off-line communication mode. It is an important capability to record the data in case of communication failures (for example). It also adds the capabilities to have a complete history of logged data, a network independent device which can automatically store the data for further transition and enabling the transfer of data for further processing without the actual device being presented. Fig. 75 shows the SPI mode bus connection schematic and breadboard design

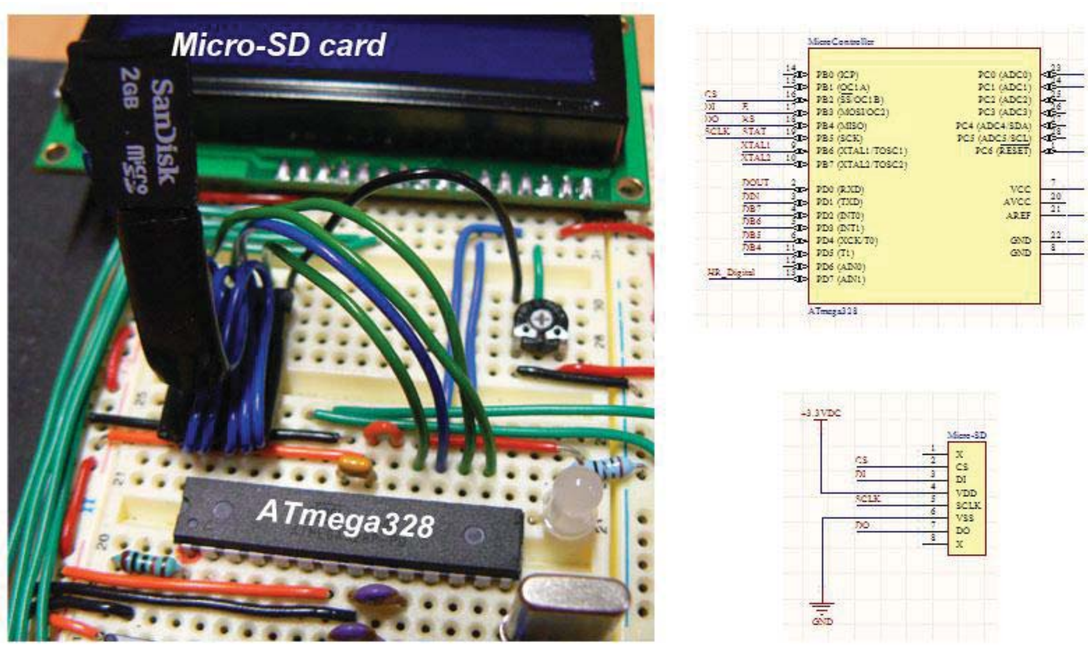


Fig 75: Connecting Micro-SD card to ATmega chip

4.8. Modular design of the prototype and PCB designs

The design is considered to be modular. This means each component of the system can be detached from the system without having an effect on the entire system. This makes the sensor easy to maintain and debug at the lower cost. The major components of the system are labeled and described as follows:

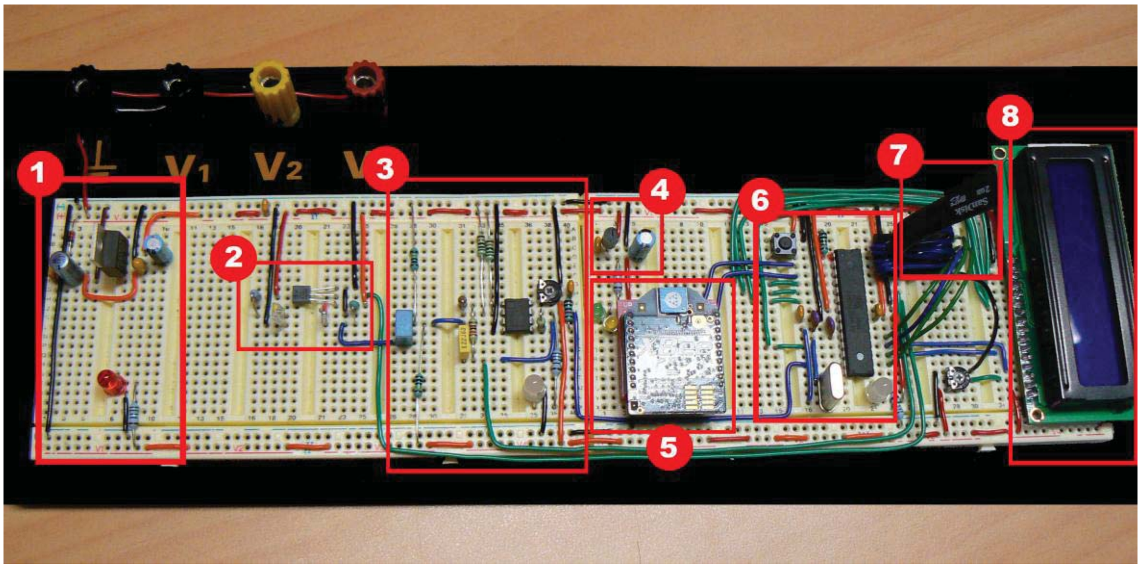


Fig 76: Breadboard design with standalone Arduino

(1) Fixed 5.0V voltage regulator: The voltage regulator supplies a fixed +5V output to the system using a LM2940CT-5 low dropout voltage regulator

(2) IR transmitter/receiver and temperature sensor: They are used to collect the heart rate signals and body temperature. The temperature sensor is connected directly to the analogue input of the micro-controller

(3) Heart beat detection circuit: It filters the data captured by the phototransistor, amplifies them, compares them with a threshold level and generates two analogue and digital signals

(4) Fixed 3.3V voltage regulator: The voltage regulator supplies a fixed +3.3V output to the XBee module using a LE33

(5) XBee module: It is connected to the micro-controller to transmit and receive the data

(6) Standalone Arduino: It uses an ATmega328P-PU DIP 24 micro-controller chip.

(7) Micro-SD card: It is connected directly to the micro-controller to increase the memory and store the data

(8) LCD display: An optional LCD display is used for displaying the heart rate and the temperature readings

4.8.1. PCB top layer

This layer is used to hold the XBee module, 3.3V voltage regulator and LED's (indicating power and heartbeats) and XBee module. In addition, a copper plate is placed as a reset button. The copper can be oxidized with time (effect of moisture for example. One solution would be to replace it with a push button key). In addition, a ground plane is placed under the XBee module to minimize any interference caused by the RF signals[1]. In addition, a 100nF decoupling capacitor is placed as close as possible to the XBee module to minimize any power source noises. Fig. 77 and Fig. 78 show the final design of PCB top-layer:

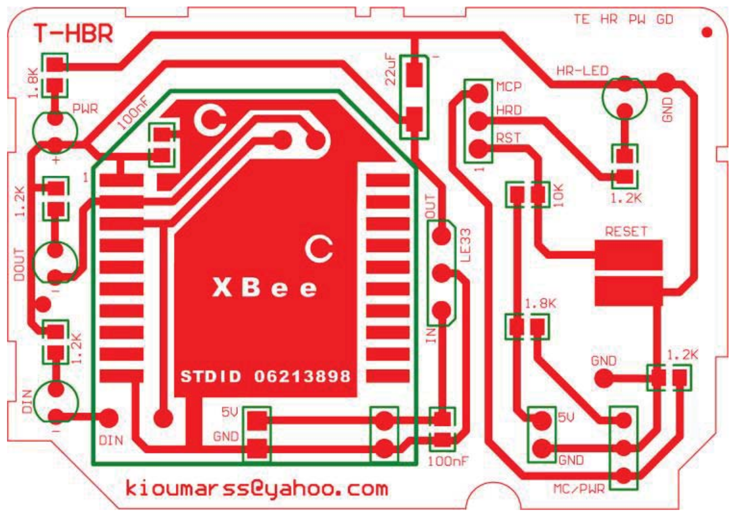


Fig 77: PCB top layer

Fig 78: Assembled top-layer PCB board

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[1] Digital signals changes by 1 to 2 volts while analogue signals can be changed by some micro-volts

4.8.2. PCB bottom layer

This layer is used to hold the micro-controller, Micro-SD card connector and heart rate sensor. Two 100nF decoupling capacitors are placed close to the ATmega chip and one 100nF capacitor close to the LM358 op-amp. Fig. 79 and Fig. 80 show the final design of PCB bottom-layer:

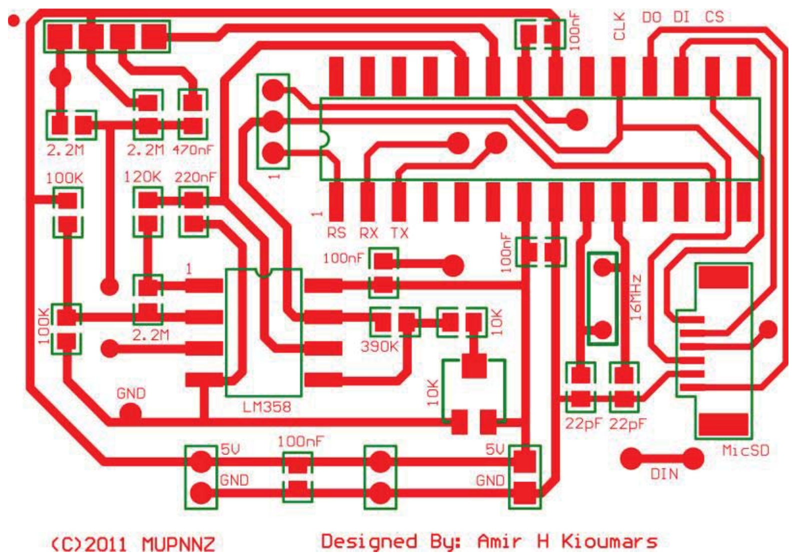

Fig 79: PCB bottom layer

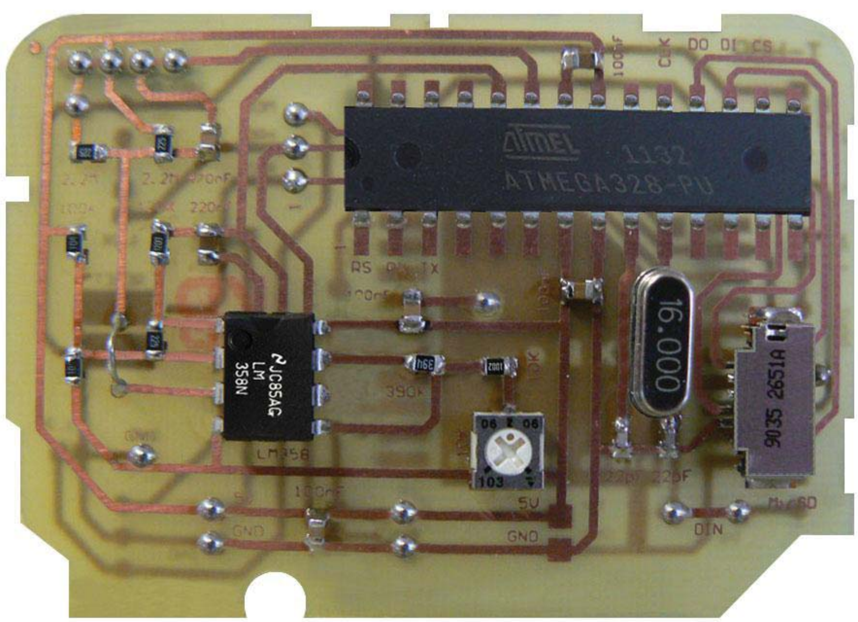

Fig 80: Assembled bottom-layer PCB board

4.9. Hardware power source

The sensor is designed to work wirelessly to monitor the human heart rate and body temperature. Therefore, there is a need for a suitable power source for the system. A suitable option for these kinds of devices is to use a rechargeable battery. These types of batteries can to charged multiple times, reducing the cost of replacing the battery over time.

4.9.1. Nickel-Cadmium batteries

The first generation of rechargeable batteries, the Ni-Cd (Nickel-Cadmium) types have been on the market for decades. Besides the fact that they are rated 1.2V compared to the 1.5V alkaline batteries, they have a disturbing memory effect. This means, if they were recharged before being completely depleted, they would never reach their full capacity again. This would require starting the next charging cycle a bit sooner, sacrificing further capacity. NiCd batteries are used in two-way radios, emergency medical equipment, professional video cameras and power tools. The ultra-high-capacity NiCd has the capacity of up to 60 percent higher than the standard NiCd. This can be done by packing more material that is active into the cell; however, length of cycle is compromised. The standard NiCd needs proper care to attain longevity. Table 13 shows the advantages and limitations of the standard NiCd[1].

Advantages	-Fast and simple charging even after prolonged storage -High number of charge/discharge cycles; provides over 1,000 charge/discharge cycles with proper maintenance -Good load performance; rugged and forgiving if abused -Long shelf life; can be stored in a discharged state -Simple storage and transportation; not subject to regulatory control -Good low-temperature performance -Economically priced; NiCd is the lowest in terms of cost per cycle -Available in a wide range of sizes and performance options
Limitations	-Relatively low specific energy compared with newer systems -Memory effect; needs periodic full discharges -Environmentally unfriendly; cadmium is a toxic metal and cannot be disposed -High self-discharge; needs recharging after storage

Table 13: Advantages and limitations of NiCd batteries[2]

[1] Reference: batteryuniversity.com/learn/article/Nickel_based_batteries

[2] Reference: www.batteryuniversity.com

4.9.2. Nickel-Metal-Hydride batteries

The Nickel-Metal-Hydride (Ni-MH) technology minimizes the memory effect and promised a thousand discharge/charge cycles without a very significant loss of capacity. However, these types of batteries suffer from self-discharge. This means if they are not used over time, while they are fully charged; there will be little capacity left.

Advantages	-30–40 percent higher capacity than a standard NiCd -Less prone to memory than NiCd -Simple storage and transportation; not subject to regulatory control -Environmentally friendly; contains only mild toxins -Nickel content makes recycling profitable
Limitations	-Limited service life; deep discharge reduces service life -Requires complex charge algorithm -Does not absorb overcharge well; trickle charge must be kept low -Generates heat during fast-charge and high-load discharge -High self-discharge; chemical additives reduce self-discharge at the expense of capacity -Performance degrades if stored at elevated temperatures; should be stored in a cool place at about 40 percent state-of-charge

Table 14: Advantages and limitations of NiMH batteries[1]

4.9.3. Lithium-ion batteries

The Lithium-Ion (Li-ion) batteries can be found in most electronic devices with rechargeable batteries. They have a 3.6V output rating instead of the 1.5V, which would burned out most of the electronic devices.

4.9.3.1. Overcharging Lithium-ion

Li-ion operates safely within the designated operating voltages; however, the battery becomes unstable if inadvertently charged to higher than specified voltage. The cell pressure rises, and if the charging is allowed to continue, the current interrupt device (CID) responsible for cell safety disconnects the current at 1,380kPa (200psi). If the pressure rises further, a safety membrane bursts open at 3,450kPa (500psi) and the cell might eventually catch fire[2].

[1] *Reference: www.batteryuniversity.com*

[2] *Reference: batteryuniversity.com/learn/article/charging_lithium_ion_batteries*

4.9.3.2. Over-discharging Lithium-ion

"Li-ion should never be discharged too low, and there are several safeguards to prevent this from happening" (Apple website, retrieved 2011).The equipment cuts off when the battery discharges to about 3.0V per cell, stopping the current flow. If the discharge continues to about 2.70V per cell or lower, the battery's protection circuit puts the battery into a sleep mode.

Battery manufacturers ship batteries with a 40 percent charge. The low charge state reduces aging-related stress while allowing some self-discharge during storage. To minimize the current flow for the protection circuit before the battery is sold; advanced Li-ion packs feature a sleep mode that disables the protection circuit until activated by a brief charge or discharge. Once engaged, the battery remains operational and the on state can no longer be switched back to the standby mode.

4.9.4. PowerGenix NiZn batteries

Another type of rechargeable battery technology is the PowerGenix NiZn. Although they are not revolutionary, they do have a 1.6V output rating compared to the 1.2V that the legacy technologies offered. In most cases, that is not concern, but it will be a matter if there is a device that is sensitive and requires getting 1.5V fed to it.

4.9.5. Selected battery

Table 15 shows an overview of Ni-CD, Ni-MH, Li-ion and Ni-Zn batteries:

	Ni-Cd	Ni-MH	Li-ion	Ni-Zn
Main brand	Many	Many	Li-ion	PowerGenix
Technology	Ni-Cd	Ni-MH	Li-ion	Ni-Zn
Rechargeable	Y	Y	Y	Y
Current	High	High	High	High
Charger type	General	General	Dedicated	Dedicated
Voltage	1.2	1.2	3.6	1.6
High current devices	Y	Y	Y	Y
Heavy duty	Y	Y	Y	Y
Standby for months	N	N	Y	N
Voltage sensitive devices	N	N	Y	Y
Work with different chargers	Y	Y	N	N

Table 15: Batteries overview

Since the sensor device requires 5VDC to operate and the booster converter needs at least 2.4VDC input in order to boost the voltage to 5VDC, therefore, among the above batteries, the Li-ion is chosen due to the following reasons:

- 3.6V package
- Standby for months
- Do not have the memory effect like Ni-Cd batteries
- Can be charged through a USB port using a special charger
- Light in weight and cheap
- Widely used in sensitive electronic devices
- Can be easily connected to power cell booster/charger (next section) which allows the battery to be charged through all kind of USB ports as well as DC power supply
- Can be easily replaced

4.10. PowerCell charger-booster

The PowerCell board from Sparkfun Electronics[1] is a single cell Lithium Polymer/Ion (LiPo/Li-ion) boost converter (to 3.3V and 5V). In addition, it has a micro-USB charger on-board. The board comes with a JST connector for a single cell LiPo battery, a micro-USB connector for the 5V charge input, and selectable 3.3V and 5V output pins. It also has two charge pins in order to use another 5V power source. The micro-USB charger uses the MCP73831[2] and allows charging a 3.7V LiPo at a rate of 500mA. The MCP73831/2 devices are highly advanced linear charge management controllers for use in space-limited, cost-sensitive applications. According to its datasheet, the MCP73831/2 employs a constant-current/constant voltage charge algorithm with selectable preconditioning and charge termination.

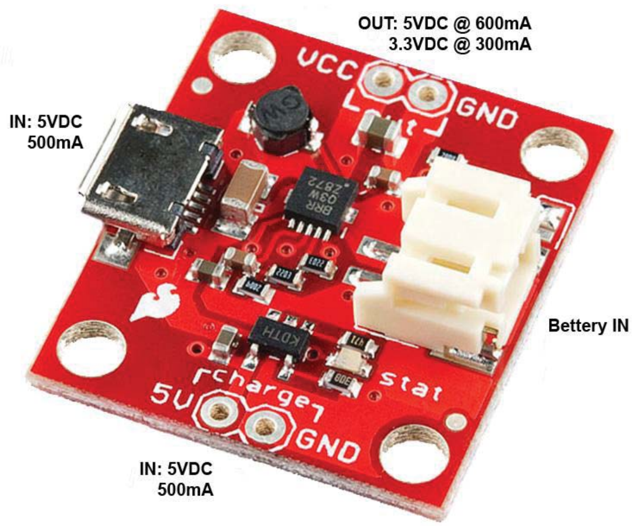

Fig 81: PowerCell charger - booster

The boost converter is based on the TPS61200[3] from Texas Instruments (TI) and has solder jumper selectable 5V and 3.3V output and an under voltage protection of 2.6V. As this board does not have reverse polarity protection, it is required to add a diode in the positive input. It has under-voltage lock out at 2.6V, quiescent current less than 55uA and an over temperature protection. The TPS6120x devices provide a power supply solution for products powered by a single-cell, two-cell, or three-cell alkaline, NiCd or NiMH or one-cell Li-ion or Li-polymer battery. The device provides output current up to 600mA at a 5V output while using a single-cell Li-ion or Li-Polymer battery. The boost converter is based on a fixed frequency, pulse-width-modulation (PWM) controller using synchronous rectification to obtain maximum efficiency. As the developed sensor requires 5V input to operate, a 3.7V Li-ion battery is used in conjunction with PowerCell to boost the output voltage to 5V at the rate of 600mA. The PowerCell board minimized the use of a 5V voltage regulator and an external charger for Li-ion battery.

[1] *Reference: www.sparkfun.com*

[2] *Appendix I: MCP73831/2 (Miniature single-cell, fully integrated Li-ion/Polymer charge/controllers)*

[3] *Appendix I: TPS612XX booster converter*

4.11. Sensor error factors

Although the prototype has many advantages including cost effectiveness, lightness and ease of use for everyone, there are several factors which may cause errors in measurement need to be taken into account when using the sensor:

- If users have some special material on their measuring site such as nail polish or covered by reflectance material, it may absorb the light emitted from the LED and change the light transmitted though the body.
- Body motion may cause a lot of noises which will reduce the reliability of the device and error in readings.
- If the blood flow is blocked due to pressure on arms or fingers, correct measurement becomes impossible.
- The device can cancel out the effects of ambient lights. However, if the light becomes too strong, the device might only cancel out some of effects and this may cause errors.
- If the sensors are not properly attached on the measuring site, it may detect a variety of noise, resulting in inaccurate measurement.

4.12. Sensor cost analysis

The total cost and size of the sensor are two considerable points in developing this sensor. A large portion of the sensor cost is due to the use of XBee radio and charger-booster. The cost of using the XBee radio can only be reduced if the sensor is produced on a large scale. Although few other radio modules exist at the lower price, the need to have a reliable and secure communication in wireless health devices, led to the use of an XBee radio. Any cost reduction that might increase the risk of putting life in danger must be eliminated. Charger-booster can be built using existing components in the market, which will reduce the cost of the module by approximately 40%. The existing booster-converters are tested by the manufacture. Therefore, they will reduce the risk of using and/or charging the Li-ion batteries. The size of the sensor can be reduced by 25% by replacing the:

- DIP28 ATmega micro-controller chip with a surface mount version called '28MLF package'. The normal DIP28 ATmege is 35mm length, 8 mm width and 8 mm height while the 28MLF version of the ATmega chip is 4mm length, 4 mm width, and 1 mm height. The developed sensor is used DIP28 because it can be programmed with the Arduino UNO while 28MLF version requires special board in order to be programmed.
- LM358 dual op-amp with the SMD version of this chip. The normal DIP8 LM358 chip is 10mm length, 8 mm width and 7 mm height while SMD version of the LM358 chip has the size of 5mm length, 6 mm width and 1.75 mm height.

The overall costs at production rates, would significantly change the pricing of the sensor[1].

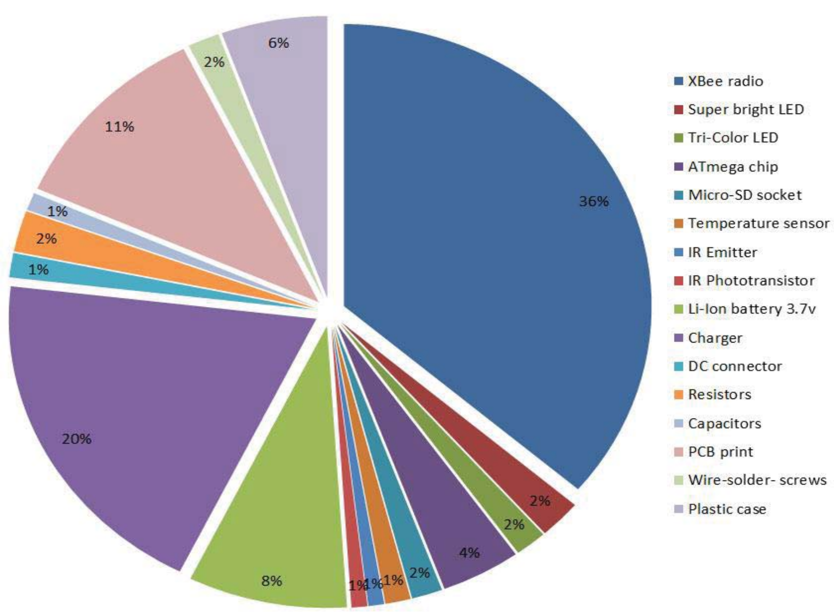

Fig 82: Sensor cost analysis

[1] Appendix F: Hardware parts/cost analysis

4.13. Sensor device power consumption

According to the components datasheets, the power consumption of each component is as follows:

- LM358 dual op-amp. The chip has a very low supply current drain 500µA
- XBee radio. The series-2 pro (S2B) has a current drawn of approximately 45mA for transmitting and receiving. By default, the device puts the module on sleep mode at all times until a proper command is received. Then the module wakes up, transmits the data and goes to sleep mode again
- ATmega328. The chip has a very low supply current drain at about 0.3mA in an active mode
- Micro-SD memory card. This device has a current drawn of 100mA per write cycle. Although it adds great features to the system it is limited by its high current drawn. For this reason, the Micro-SD card is formatted using FAT32 with 4096 bytes for allocation unit size in order to write a bigger block of data at one write cycle. This device stays OFF at all times until a proper command is received to activate it
- LEDs. These parts draw more current compared to other devices. For this reason, a series of super-bright LEDs with very high resistor values are used. Under normal circumstances, the current drawn from LEDs are about 20mA. By using the high resistor values (for example 1.8KOhm or higher) the current can be reduced by up to 60%

The maximum current drawn from the device when all components are operating is approximately 150mA. With a 1000mA Li-ion battery, the device can continually run for up to 7 hours (in the worst case). However, the idea is to save the power by not using the sensor at all times. Therefore, the software system has a function to wake up and activate the sensor whenever it is needed. The software sends a command to the device, reads the heart rate and temperature, transmits the data and then goes to sleep mode, waiting to receive another command. In this situation, as the device will not run continuously, the maximum running time of the system will increase by up to 70% (50 hours in the best case).

Considering the maximum and minimum settings parameters, which the device can operate within, the minimum and maximum running time of the system with a fully charged 1000mA Li-ion battery is about 6 hours and 45 minutes in the worst case and 50 hours and 12 minutes in the best case.

4.14. Hardware unit testing

In order to test the prototype and make sure all the components are working as intended, a series of tests have been done on each major component of the system. Like testing software, the hardware is divided into several different parts and each part tested separately. Some parts of the device such as XBee and Micro-SD card are tested by writing a simple software code[1].

An XBee module is connected to the PC as a coordinator and the second module is connected the device. A simple two-way communication code is written and uploaded to the micro-controller chip in order to send and received a test packet. The program waits for a proper command from the coordinator, then acknowledges that and prints a sample message on the serial port (which can be transmitted by the XBee). The coordinator is then checked whether the packet received matches with the expected packet.

A simple program is written to generate a set of random numbers and stores them on the Micro-SD card. By receiving a proper command from the coordinator, the data stored on the Micro-SD card, reads and transmits to the coordinator.

The device is attached to the oscilloscope and the signal strength is measured both with and without LM358 chip to make sure the device is amplifying the signal as expected[2].

[1] *Appendix B: Micro-controller unit tests*

[2] *Appendix H: Hardware test results*

CHAPTER 5 – SOFTWARE

An electronic health record (EHR), electronic patient record (EPR) or computerized patient record (CPR) is an evolving concept defined as collecting of electronic health information about individual patients systematically. It is in a digital data format that is capable of being shared across different healthcare organizations by using an embedded network-connected enterprise-wide information system [55]. EHR might be in comprehensive or summary form, including demographics, medical history, medication and allergies, immunization status, laboratory test results, radiology images, vital signs, personal stats like age and weight and billing information.[1]

5.1. Electronic health data

Its purpose can be understood as a complete record of patient encounters that allows the automation and streamlining of the workflow in healthcare settings and increases safety through evidence-based decision support, quality management and outcomes reporting. Computers are helpful in the healthcare setting, particularly hospitals. For example they are used to view imaging studies such as x-rays, CT and MRI scans. Most hospitals subscribe to online medical resources which provide quick access to updated medical information. Some of the advantages of using EHR are as follows:

- Reduction of cost: information technology is used to automate day-to-day processes, thus helping to reduce administration costs which in-turn it can free up time and money for patient care
- Improve quality of care: The implementation of EHR can help to reduce the patient sufferance due to medical errors
- Promote evidence-based medicine: EHRs provide access to clinical data for research that can accelerate the level of knowledge of effective medical practices
- Record keeping and mobility: EHR systems have the advantages of being able to connect to many electronic medical record systems

5.2. Microsoft .Net

"Microsoft .NET (pronounced as Dot Net) is an integral part of many applications running on Windows and provides common functionality for those applications to run" (Microsoft.com, retrieved 2011). In .NET all basic data types have a consistent size regardless of the language.

[1] *Reference: en.wikipedia.org/wiki/Electronic_health_record*

In any large application, many pieces of software might be written in different languages. Developers might choose to use Visual Basic (VB) to design their user interface because it is quick and easy to use. They might also choose C++ to do their computations because it can easily handle complex data structures. But the major difference lies in error handling. VB uses one form of error handling while C++ uses a different form. The problem arises when the VB user interface asks the C++ computation engine to calculate a value and in the process of calculating the value, C++ finds an error. Both VB and C++ have very good error handling abilities but they only work within the language. They do not work across different languages. In .NET, regardless of what language is using, there is an 'exception' object, which is the foundation for error handling and it is able to communicate errors within different languages.

5.3. C# programming language

C# (pronounced as C sharp) is a programming language, which is designed by Microsoft in 2001. It is a programming discipline with the following features[1]:

- Multi-paradigm programming language - supports more than one programming paradigm
- Encompassing strong typing - specifies one or more restrictions on how operations involving values of different data types can be intermixed
- Imperative - describes computation in terms of statements that change a program state
- Declarative - expresses the logic of a computation without describing its control flow
- Functional - treats computation as the evaluation of mathematical functions and avoids state and mutable data
- Generic - algorithms are written in terms of to-be-specified-later types that are then instantiated when needed for specific types provided as parameters
- Object-oriented/class-based
- Component-oriented - emphasizes the separation of concerns with respect to the wide-ranging functionality available throughout a given software system

According to the Microsoft research team, real-world experience shows that some applications continue to require "native" code, either for performance reasons or to interoperate with existing application programming interfaces (APIs). Such scenarios may force developers to use C++ even when they would prefer to use a more productive development environment. C# addresses these problems by including native support for the Component Object Model (COM) and Windows-based application programming interfaces and allowing restricted use of native pointers.

[1] *Reference: www.microsoft.com/Csharp*

By default, in C# every object is a COM object. There no need to explicitly implement "IUnknown" and other COM interfaces. Instead, those features are built-in. Similarly, "C# programs can natively use existing COM objects, no matter what language was used to author them" (Microsoft.com, retrieved 2011). C# includes a special feature that enables a program to call out to any native API. It is allowed to use pointers and traditional C/C++ features such as manually managed memory and pointer arithmetic inside a specially marked code block. This is a big advantage over other environments. C# is an elegant, simple, type-safe, object-oriented language that allows enterprise programmers to build a breadth of applications. It also gives the capability to build durable system-level components by virtue of the following features[1]:

- Full COM/platform support for existing code integration
- Robustness through garbage collection and type safety
- Security provided through intrinsic code trust mechanisms
- Full support of extensible metadata concepts

C# interoperates with other languages across platforms, with legacy data, by:

- Full interoperability support through COM+ 1.0 and .NET Framework services with tight library-based access
- XML support for Web-based component interaction
- Versioning to provide ease of administration and deployment

C# eliminates "forgetting to initialize a variable" errors (by initializing them before use), unsafe casting and consistent error handling through exceptions. The end result is a language that makes it much easier for developers to write and maintain programs that solve complex business problems. C# extends the idea of 'software reuse', allowing developers to concentrate on the specialities without having to implement of every application. C# enables developers to create windows applications easily, use pre-packaged controls as buttons, textboxes, scrollbars and communicate with serial communication ports through simple set of APIs, reducing the overhead of serial port communication programming

[1] *Reference: msdn.microsoft.com*

5.4. Database

A database is a collection of related data, which are organized so that useful information may be extracted. In healthcare, medical personnel for patient care recording, monitoring the patient's status and treatment advice may use database[1].

5.4.1. Oracle MySQL and Microsoft SQL Server

MySQL, a Relational Database Management System (RDBMS) developed by MySQL AB (a subsidiary of Oracle), is the world's most popular open-source database that runs as a server providing multi-user access to a number of databases. "To date, reliability and high-performance characteristics of the MySQL and Windows combination are strongly confirmed" (Robin Schumacher, MySQL's director of product management, 2011).

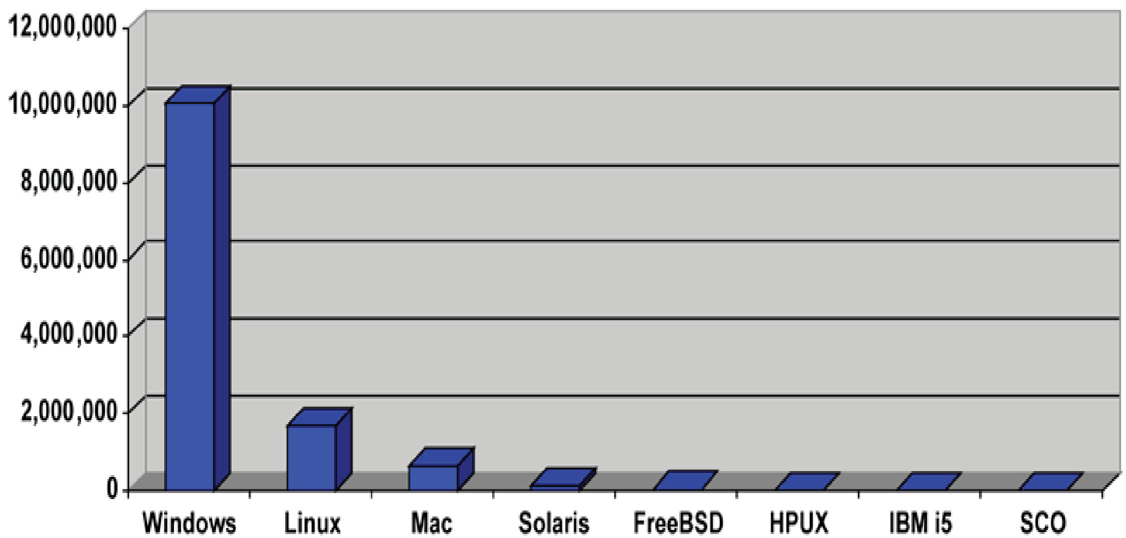

Fig 83: My-SQL downloads statistics from April 2008 to April 2009[2]

Microsoft SQL Server, a relational database server developed by Microsoft, is a software product whose primary function is to store and retrieve data into the database on the same computer or across the network (including the Internet). Both MySQL and SQL Server are powerful database management systems (DBMSs) which are widely used by database administrators. The following points are some of the advantages of using MySQL compared to Microsoft SQL Server:

---

[1] *Computer Science department of Stanford University of USA*

[2] *Reference: dev.mysql.com*

5.4.1.1. MySQL features

The most obvious and enduring difference between MySQL and SQL Server is the price tag. MySQL and its attendant client libraries are free under the GNU Public License, though the system is also released under a more proprietary license when needed. Because of its low cost and broad support, many commercial applications use MySQL as the default database backend[1]. In brief, MySQL:

- Is open-source
- It is available on two-dozen platforms (32 and 64 bit) including Windows such as Linux RedHat, SuSE, Fedora, Solaris, HPUS, AIX, SCO, FreeBSD and Mac OS
- It has pluggable storage engine architecture (MyISAM, InnoDB, Merge, Memory, Archive, Cluster)
- It has an unique query cache (stores query and result set)

5.4.1.2. MySQL installation and configuration

Installing software becomes a major factor when many servers need to be commissioned and upgraded. Microsoft SQL Server 2008 Enterprise software size is about 1.6GB in size. It also requires additional 150MB libraries for .NET framework to be installed which are the same size as the full MySQL 5.1 for Windows. In a simple test, both MySQL and MySQL Server are installed on the same PC. The results indicate that MySQL can be installed in about 5 minutes, but the SQL Server installation takes much longer (depending on the server is used). The .NET framework installation time takes approximately 5 times longer than MySQL Server installation.
Another install and configuration consideration is having multiple instances of a database server on one machine. Developers can have a full-featured MySQL Server installed on a PC without having to use Windows Server like is sometimes required for various versions of SQL Server Enterprise. Lastly, when it comes to configuration, most SQL Server database administrators (DBAs) set their configuration parameters via the SQL Server Management Studio whereas MySQL DBAs manually edit the “my.cnf” file. Note that, like SQL Server, most of the configuration parameters for MySQL are dynamic and can be set/immediately changed via a SET GLOBAL statement at a MySQL command line prompt.

5.4.2. MySQL in healthcare

Hospitals and medical practitioners have had to contend with numerous challenges such as interoperability, privacy, and business process pressures that have slowed their investment in

[1] *Reference: www.oracle.com*

information systems as compared to other industries. But new market drivers, both political and economic, are forcing the healthcare industry to turn to IT to improve its effectiveness and efficiency. In fact, one of the top priorities in the healthcare industry is to broaden the use of electronic records and other health information technology to help reduce costs and dangerous medical errors, and improve patient safety.

Healthcare applications including practice management solutions, electronic medical records, monitoring equipment and digital imaging systems all rely on a clinical data repository, which requires a high-performance transactional database for processing patient information. MySQL is the cost-effective, high performing and reliable data repository used by many of the leading solution providers including “eClinicalWorks” and “MacPractice”.

MySQL provides the following significant benefits:

- High Performance, enabling products to capture more clinical data as and when needed. This provides the healthcare providers the ability to do more granular analysis and the ability to grow to meet increasing demands over time.
- Reduced COGS and Improved Profitability by using a highly cost efficient database that allows vendors to offer healthcare solutions at a fraction of the cost of competing solutions. MySQL's lower costs provide margin flexibility, so pricing can be more easily set to appeal to price-sensitive Small to Mid-Size payers.
- Multi-Platform Support MySQL supports over 20 platforms making it ideal for the healthcare industry in which a wide variety of platforms are used, including Mac OS, Windows, and increasingly Linux. Platform flexibility allows healthcare solution providers to more easily extend the size of their addressable markets.
- Ease of Installation & Configuration, so healthcare providers needn't be database experts to get a complete solution up-and-running quickly using an out-of-the box configuration.
- Zero Administration, eliminating the need to hire-in costly database administration skills to maintain the database, which is particularly valuable for smaller practices, which often lack full-time IT support.
- High Reliability so all of the data is captured at all times to meet regulatory requirements and to ensure providers have the information they need to provide patients with the highest levels of care.

5.5. Micro-controller programming

There are many micro-controller s and their platforms available for physical computing. Arduino simplifies the process of working with micro-controller. In addition, Arduino programming language offers some advantages compared to other micro-controller programming languages:

- Cross-platform

  The Arduino software runs on Windows, Macintosh OSX, and Linux operating systems. Most micro-controller systems are limited to Windows

- Simple and clear programming environment

  Arduino programming environment is easy-to-use and flexible enough for advanced users to take advantage of using the Arduino programming language and its environment

- Open-source and extensible software / open-source community support

  The Arduino software is published as open-source tools and the language can be expanded through C++ libraries. The Arduino programming language is widely supported by the open-source community. Its libraries and resources are freely available with complete help and documentations

5.5.1. Micro-controller software block diagram

Arduino micro-controller uses ATmega chip on-board. It has 32KB flash memory and maximum of 4KB Static Ram (SRAM). SRAM limitations requires a clear understanding of the program memory usage. A simple diagram of micro-controller software plan is shown in Fig 84.

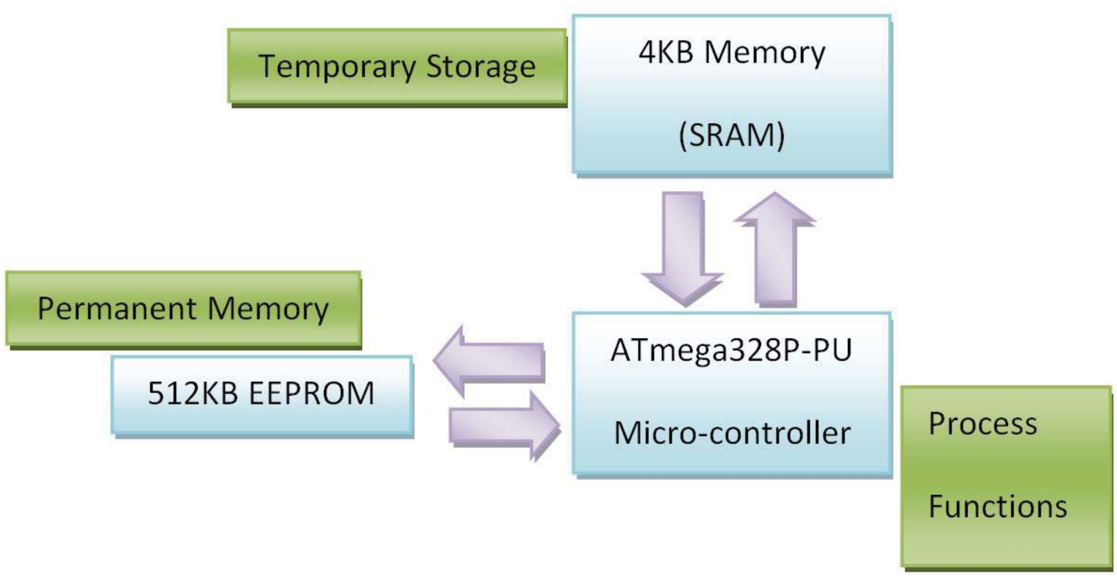

Fig 84: Micro-controller software flow diagram

The micro-controller processed the data based on the defined functions. The results of processing will be stored in the SRAM. Some of the 4KB memory is reserved for the micro-controller therefore the actual available memory is slightly less than 4KB (about 3.8KB is free and available to use by the Arduino software). In addition to the SRAM, there is a 512KB EEPROM[1] available which allows the storage of a small amount of data permanently. This can be done using Arduino EEPROM library.

Using the EEPROM memory has a great advantage. It is a permanent memory and can hold the data even when the power is removed. So if the micro-controller is required to use the pre-programed data (for example change the program settings), there is no need to upload them into the micro-controller every time. Therefore, the EEPROM is used to store the patient basic information such as first, last names, date of birth, gender, identification number (health ID for example), temperature and heart rate sensor settings and the Hardware Unique Identification Number (HUIDN). The HUIDN is very important. It is programed by the manufacturer in order to label the device for using within the network. The HUIDN is the key to transmitting and receiving the data to and from the micro-controller. Any alteration to this key will make the hardware device unusable.

5.5.2. Micro-controller software functions

The major components of the software are as follows:

- A structure to store and retrieve the data to and from the micro-controller EEPROM
- Main loop which continuously monitors the incoming packet, analyses it and take proper action
- A reset method which resets the micro-controller (soft reset by jumping to address 0) in order to clear the memory and avoid memory leaking
- EEPROM read and write methods to read and store the data permanently
- Temperature and heart rate method
- Micro-SD card functions to retrieve memory card information or log the data
- Read and write from and to the Micro-SD card

5.5.3. Heart rate function

Heart rate function gets two values which indicate whether the user required the digital and/or analogue value to be calculated. The analogue signal is used to demonstrate the heart rate signal and the digital output is used to calculate the heart beats over a period of time.

[1] *Electrically Erasable Programmable Read-Only Memory and is a type of non-volatile memory used in computers and other electronic devices to store small amounts of data that must be saved when power is removed*

```
/*********************************************************
 *  Calculate the heart rate by reading the digital pin 7
 *********************************************************/
int getHeartRate (boolean getDigitalOutput, boolean getAnalogOutput)
{
  HRCount =0;                              // initialize the variables
  HRDReading =0;

  isBeated = true;                         // control the heart beats

  currentMillis = millis();
  targetMillis = currentMillis + atoi (hs);

   while (currentMillis < targetMillis)    // loop until target time is meet
  {
    if (getDigitalOutput)
      HRDReading = digitalRead (HRDSP);

    if (getAnalogOutput)                   // if analogue samples are required
      Serial.println (analogRead(HRASP));

    if (HRDReading == 0)                   // if no heart beat is detected
    {
      digitalWrite (ledPin, LOW);          // turn the Arduino onboard led off
      isBeated = true;                     // set true to detect the next heart beat
    }

    if (HRDReading != 0 && isBeated)       // if heart beat detected and was not counted before
    {
      digitalWrite (ledPin, HIGH);         // turn the Arduino onboard led on
      HRCount++;                           // count the beat
      isBeated = false;                    // set it as visited beat
    }

    currentMillis = millis();
    delay (atoi (hd));
  }

  if (getDigitalOutput)
    Serial.println ((HRCount * (int) (60000 / atoi (hs))));

  printAndReset ("", 250);
}
```

Heart rate time interval

Heart rate analogue

Heart rate sample delay

Heart rate digital

Fig 85: Micro-controller heart rate function

5.5.4. Temperature function

This function is used for calibration[1] as well as calculating the skin temperature. Then the Burton's equation is applied to the calibrated value to get the more accurate reading close to the internal body temperature. The value of the sample size indicates how many sample needs to be taken and temperature sample delay indicates how much delay is required between each sample. These values can be programed and stored in EEPROM.

[1] *See section 3.6.7. Temperature calibration*

```
/***********************************************************************
 *  Get the temperature from TMP36 sensor connected to analogue pin 1
 ***********************************************************************/
void getTemperature()
{
  temp =0;
  voltage =0;
  temperature =0;

  for (i=0; i< atoi(ts); i++)        Temperature sample size
  {
    //getting the voltage reading from the temperature sensor
    int reading = analogRead (TPASP);

    // converting that reading to voltage
    voltage = reading * 5.0;

    voltage /= 1024.0;                             Temperature sensor calibration

    // converting from 10mv/degree with 500mV offset ((volatge - 500mV) * 100)
    temperature = (voltage - 0.5) * 100 ;

    t = t + temperature;
    delay (atoi (td));                Temperature readings delay
  }

  // get the average over readings
  t = t / atoi (ts);

  // calculate internal body temperature              Burton's equation
  // (0.64 * Tcore + 0.36 * Tskin) where Tcore ~ 37 'C
  t = 0.64 * 37 + 0.36 * t;

  Serial.println (t);
  printAndReset ("", 250);
}
```

Fig 86: Micro-controller temperature function

The temperature sensor read values over the time and averages the readings to get the analogue temperature value. The final value of the temperature is printed on serial port which will transmitted by XBee module.

5.5.5. Structured EEPROM access

On an Arduino or other AVR, EEPROM access is not easy in terms of storing different types of data. Arduino EEPROM is simple but it only reads/writes single bytes. It has two template functions read and write defined by the Arduino libraries. However, using these functions require knowing the data offset. Also, these C++ templates are a bit tricky to use. On a deeper level, AVR library has a more complex API for other kinds of integers and buffers. However, it still needs to remember the offset and size of the data. There is a keyword called 'EEMEM' which flags the data as they are stored in the EEPROM but it is still require to know the data size and offset. Therefore, a single structure is required to represent the entire contents of data to store and retrieve in and out of EEPROM. It uses micros to read and write fields.

5.5.6. Lightweight strings

Since Print was introduced with ‘Arduino 0012’, several classes, including ‘HardwareSerial’, ‘LiquidCrystal’, ‘Ethernet Client/Server’ and ‘NewSoftSerial’ have been written to leverage its text rendering engine. But getting formatted text to output devices requires either writing custom code or turning to expensive alternative solutions like sprintf().

LString (“Print-to-String”) is a new lightweight Print-derivative string class that renders text into a character buffer. They allow the Print renderer for any devices, even those that do not directly support Print-style text formatting. LStrings do not have their own buffers. Instead, they rely on pre-allocated static buffers that are passed in at the point of construction. Unlike Strings, they do not allocate memory dynamically, even when the result of a print(), assignment or concatenation operation seems to exceed the current buffer’s size. In these cases, the excess data is simply discarded and the string correctly terminated. Because of these constraints, LStrings has the following advantages compared to String:

- They will never cause a buffer overflow
- A string’s buffer will always be valid memory, for example the original buffer
- Buffers will always contain valid (for example NULL-terminated) C string data

5.5.7. Data packet

The process of communication with the micro-controller requires clear time synchronization. Transmitting and receiving also requires power. Therefore, sending a chunk of data at once will reduce the power consumption and the need for synchronization. Therefore, in order to have a more reliable and faster communication, a custom data packet is introduced. This data packet is an LString type with 128bytes in length. Fig. 87 shows the data packet fields:

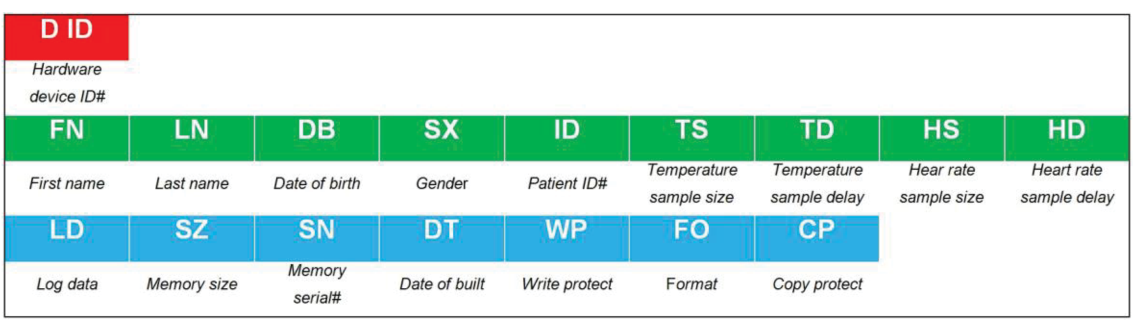

Fig 87: Data packet block diagram

The changeable fields can be programed and stored permanently in micro-controller EEPROM until overwritten. The rest of fields are read-only.

	Length (Byte)	Description	Changeable
D ID	10	Device id number – programed by manufacturer	N
FN	30	Patient first names	Y
LN	20	Patient last name	Y
DB	10	Patient date of birth	Y
SX	1	Patient gender	Y
ID	10	Patient health ID (or any other ID number)	Y
TS	5	Temperature sample size	Y
TD	5	Delay between each temperature sample	Y
HS	5	Heart rate sample	Y
HD	5	Delay between each heart rate sample	Y
LD	1	Flag to enable/disable write to Micro-SD card	Y
SZ	8	Micro-SD card size	N
SN	8	Micro-SD card serial number	N
DT	7	Micro-SD card date of manufacture	N
WP	1	Micro-SD card write protect	N
FO	1	Micro-SD card format	N
CP	1	Micro-SD card copy protect	N

Table 16: Data packet description

Depending on the transition flow, the data packet can be constructed by micro-controller or host PC. The data packet is the heart of the two-way communication. It is carefully designed based on ATmega328 memory limitations. Host PC broadcasts the data packet to entire network nodes. All the hardware devices receives the packet, looks at the header to extract the hardware ID. If this ID is matched with the pre-programed 'hardware ID' inside the micro-controller, then the packet will be examined otherwise it will be discarded.

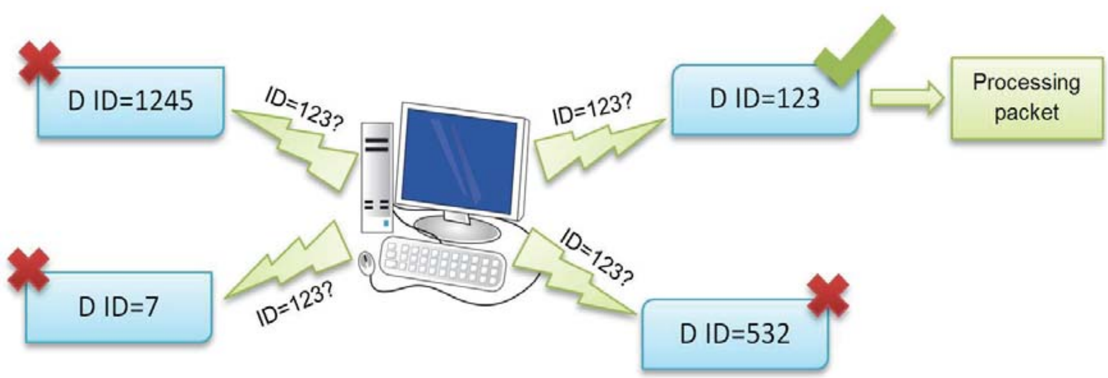

Fig 88: Data packet broadcasting

5.5.8. Communication commands

Data packet fields can be programmed at once or individually. Programming these elements at once can be done by the THB-R software[1]. It is also possible to change the value of each field by using Arduino software command line, Windows hyper-terminal or any other similar software. Each hardware device has a unique identification number (D ID) which is predefined as an un-changeable field and it is hard coded within the Arduino code. The last 6 fields of the packet also are read-only. Therefore, for the remaining changeable fields, the following command syntax can be used:

<*return value/acknowledgment*> command [device-id] <*arg*> <*value*>

Table 17 and Table 18 are shown the micro-controller acceptable commands, abbreviations, descriptions, arguments, values and returning values/acknowledgment by each command. The following examples show how to use some of these commands:

g↵
123456789
(Returns the device-id)

g 123456789↵
Amir, Kioumars, 1975-07-15, M, G3170915, 100, 10, 10000, 10, 1
(Reads the eeprom to get the patient information. Last bit ‘1’ indicates that the memory card is installed on the device)

p 123456789 fn Mark↵
fn
(Updates the first name and replace the existing value with ‘Mark’ and acknowledge it)

p 123456789 db 1986-01-12↵
db
(Updates the date of birth and replace the existing value with ‘1986-01-12’ and acknowledge it)

g 123456789↵
Mark, Kioumars, 1986-01-12, M, G3170915, 100, 10, 10000, 10, 1
(Reads the eeprom to get the patient information to make sure the changes are applied and stored into the eeprom)

[1] *Please visit section 5.10.T-HBR software*

The spaces between command and arguments are compulsory and must be exactly one. Each command has its own unique acknowledgment which will display on the serial port.

Return value/ Acknowledgement	Command	Abbreviation	Description
return value/ Acknowledgment	g	get	query a device to get the device ID
return value	a	acquire	acquire heart rate or temperature
acknowledgment	p	program	update a field
acknowledgment	e	eeprom	EEPROM access
acknowledgment	r	reset	reset the device

Table 17: Micro-controller commands, abbreviations and description

Return value/ Acknowledgement	Command	Device ID	Arg(s)[1]	Value (type / field name / length)
device-id	g			
data packet	g	device-id		
temperature value	a	device-id	te	
Heart rate (digital)	a	device-id	hd	
Heart rate (analogue)	a	device-id	ha	
fn	p	device-id	fn	String/ first name/ 30 chars
ln	p	device-id	ln	String/ last name/ 20 chars
db	p	device-id	db	String/ date of birth/ 10 chars
sx	p	device-id	sx	String/ gender/ 1 chars
Id	p	device-id	id	String/ patient id/ 10 chars
ts	p	device-id	ts	String/ temperature sample size/ 5 chars
td	p	device-id	td	String/ temperature sample delay/ 5 chars
hs	p	device-id	hs	String/ heart rate sample size/ 6 chars
hd	p	device-id	hd	String/ heart rate delay/ 5 chars
ld	p	device-id	ld	String/ log data/ 1 char
ee	e	device-id	e	
rr	r	device-id		

Table 18: Micro-controller commands details

[1] *Arg(s): input arguments*

5.6. Software requirements

The requirements analysis is critical to the success of a software project. They must be actionable, measurable, testable, traceable, related to identified business needs and defined to a sufficient level of details for system design. Therefore, the requirement analysis of the software system has led to the following requirements:

- Measure the patient heart rate and skin temperature and collect them
- Transmit the collected information
- Able to log data on an external memory such as a memory card
- Able to program the remote hardware device wirelessly
- Able to show the patient history and update them
- Generate the temperature and heart rate graphs
- Send e-mails and text messages to the patient, his/her next of kin and other GP's
- Encrypt/decrypt data using at least five different algorithms
- Retrieve the user login information
- Register new GP, patient and hardware device
- Validate information before store them into a database
- Control the heart rate and temperature sensor parameters remotely
- Run on a local machine or server
- Backup and restore the database and be able to merge the new data to the existing database

The conceptual view of the software system is shown in Fig. 89.

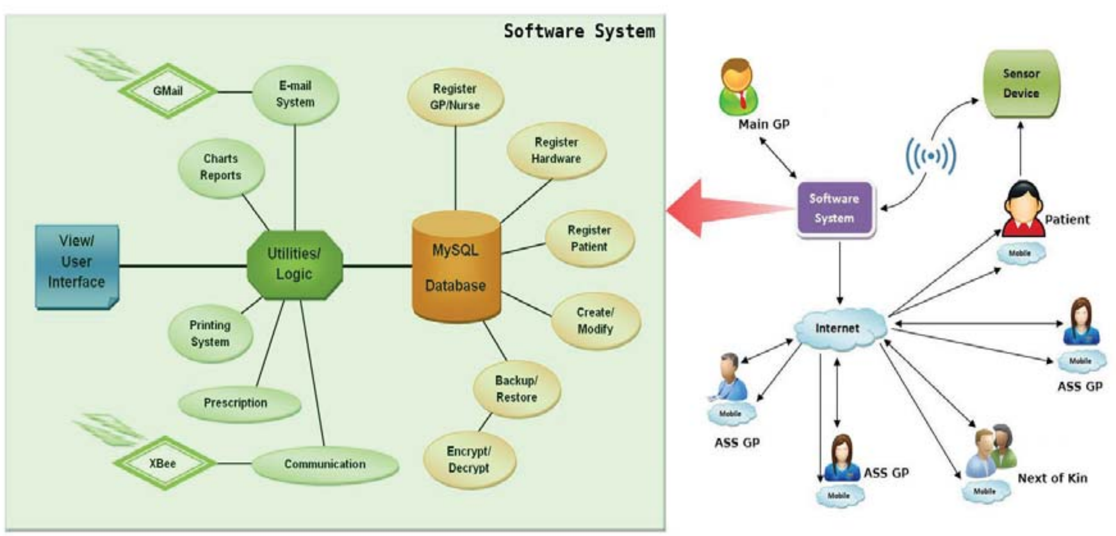

Fig 89: Conceptual view of the software system

5.7. Software system conceptual view

The software system architecture is the set of structures that are needed to reason about the entire system. It comprises software elements such as classes, relationship between them and their properties. It also refers to documentation of a software system. Documenting software system architecture facilitates about high-level of design and allows reuse of design components and patterns. It is commonly organized in views, which are analogous to the different types of blueprints made in building architecture. Functional/logic, code/module, development/structural, physical/deployment, user action/feedback and data view/persistency are some of possible views[1]. Fig. 90 shows the conceptual view of the software system architecture[2]. It consists of three main views:

- User action/feedback (view/user interface)
- Functional/logic (utilities/logic)
- Data view/persistency (MySQL database)

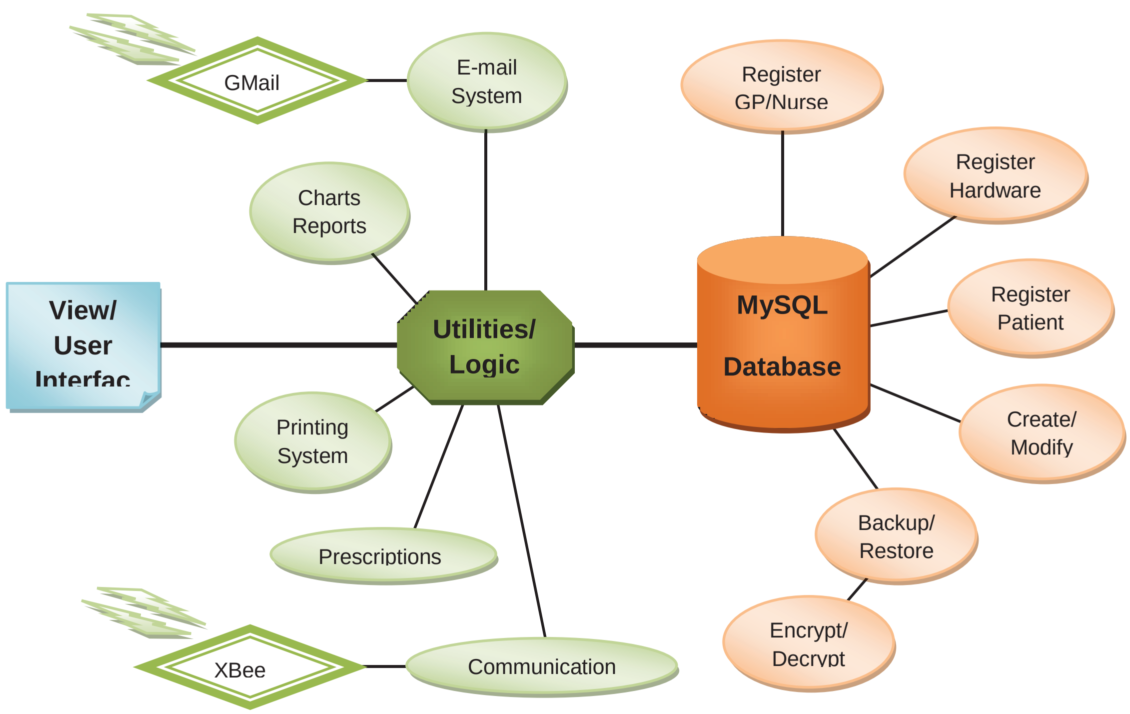

Fig 90: Software system architecture

[1] Reference: www.microsoft.com

[2] Appendix C: Software classes, methods and properties

A software development methodology or system development methodology is a framework that is used to structure, plan, and control the process of developing an information system. A good software methodology will keep the software process within the software requirements and avoid using a proper methodology will increase the cost of software development or even solving the wrong problem.

Rapid Application Development (RAD) is a software development methodology, which involves iterative development. The basic principles of RAD are as follow:

- Fast development
- Deliver of a high quality system at a relatively low investment cost
- Attempts to reduce inherent project risk by breaking a project into smaller segments
- Provide more ease-of-change during the development process
- Aims to produce high quality systems quickly sing sophisticated developments tools such as: Graphical User Interface (GUI) builders, Database Management Systems (DBMS), fourth-generation programming languages and object-oriented techniques
- Generally includes Joint Application Design (JAD), where users are intensely involved in system design, via consensus building in either structured workshops, or electronically facilitated interaction
- Produces documentation necessary to facilitate future development and maintenance
- Standard systems analysis and design methods can be fitted into this framework

5.8. Software architecture

One of the most fundamental approaches in software engineering is the “layered architecture”. It implies dividing a system into several interacting layers with certain limitations imposed on how layers may interacts. A particular case of layered architecture is the 3-tier architecture with its variations: Model-View-Controller and Model-View-Presenter.

A straight-forward and widely used approach in designing applications is the 2-tier architecture. 2-tier consists of a presentation layer and a domain layer. Domain layer classes represent the problem domain entities (for example patient) and are usually bound to some database access facilities. Presentation classes in 2-tier architecture have the following responsibilities[1]:

- Receive user input
- Make necessary calls to the domain tier
- Decide what to show next to the user
- Display output

These responsibilities are rather vast and, as a system grows, may result in a bloated presentation layer. Moreover, they logically can be divided into two groups:

- Actually presentation logic (code for perceiving input and displaying output)
- Application logic (communication with the domain tier and application flow decisions)

3-tier architecture is rather abstract. The presentation layer in this architecture is divided into presentation and logic[1]:

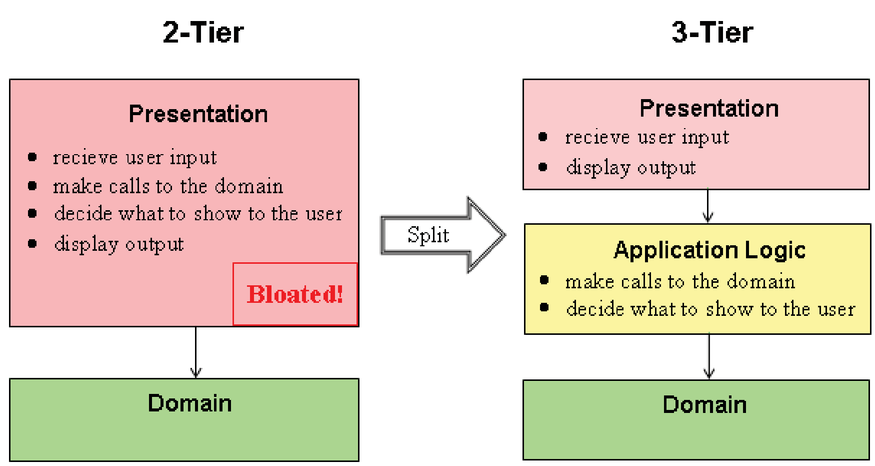

Fig 91: 2-Tier and 3-Tier architecture

A much more precise form of 3-tier architecture can be divided into two:

- Model-View-Controller (MVC)
- Model-View-Presenter (MVP)

[1] *Reference: www.microsoft.com*

The presentation layer in both MVC and MVP consists of view and application logic. For each view object, a corresponding controller exists and vice versa. Although MVC and MVP are based on a common 3-tier principle, they have the following major differences:

- In MVC, controllers receive and process user input, but in MVP views receive user input and then merely delegate processing to the corresponding controllers. Therefore the MVP pattern is better fits into the modern User Interface (UI) environments (Windows/Web forms) where view classes themselves handle user gestures.
- In MVC, controllers affect their views by changing the intermediate presentation model. This makes views "pure observers" without direct access to them. MVP on the other hand violates this "pure observers" rule by providing a direct link from a controller to its view. This makes MVP handier compared to MVC.

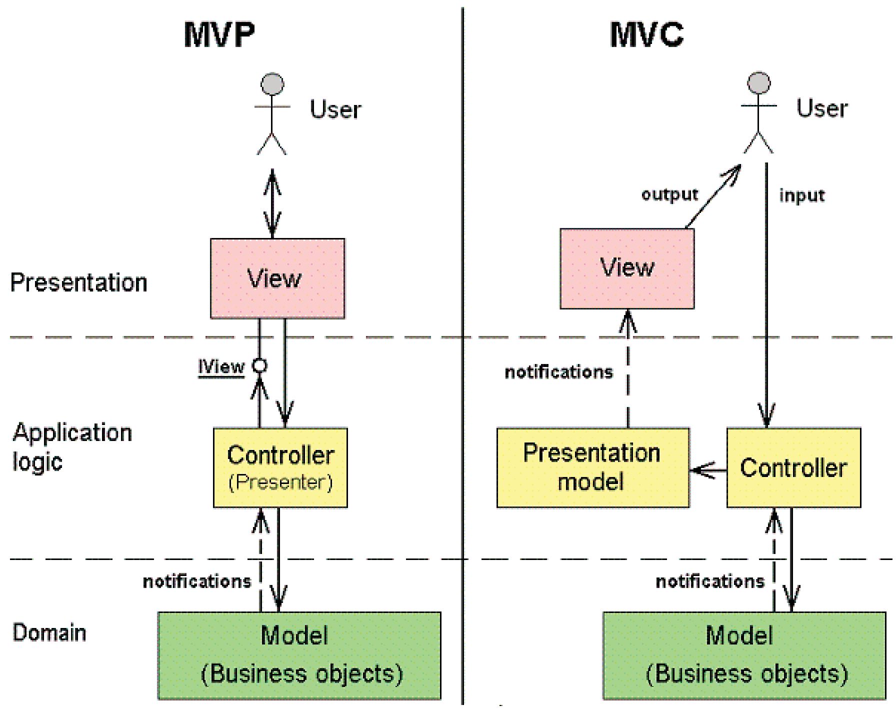

Fig 92: MVC and MVP patterns[1]

It can be concluded that the MVP pattern more attractive than MVC from the developer's point of view. MVP is designed to be an evolution of MVC and it is often refer as "sharp MVC" or "MVC#". However using MVP may not be easy. Maintaining an additional application logic layer may require considerable efforts. For example, a developer needs to take care of linking between all views and appropriate controllers. MVC# automates and takes on itself much of the work concerned with MVP usage. Thus it simplifies and speeds up the development of MVP applications. Some of the MVC# framework features are as follows:

[1] *Reference: www.microsoft.com*

- Views and controllers get connected automatically

  Developers do not have to care about associating views with their controllers. MVC# framework automatically establishes links between views and corresponding controllers.
- Multiple GUI platforms supported

  MVC# allows targeting different GUI platforms (Windows, Web, Silverlight, etc.) Thus the same application can be used with quite different presentation layers - one for Windows, the other for Silverlight or Web environment
- Platform-independent navigation to views

  To make application logic fully independent of the presentation layer, MVC# provides a platform-independent way of navigating to views. Instead of activating a Windows form or redirecting to a Web page a developer should simply call a uniform Navigator.Navigate(...) method.

MVC# framework frees developers from much of extra work required in construction of Model-View-Presenter applications. It allows creating flexible MVP-based application with almost no extra cost.

5.9. Database design

The database (persistency layer) is used to store the data in a digital form. The data captured by the remote sensor is sent to the host PC and must be stored in an appropriate way. These data are raw and need further processing in order to be able to interpreted them. Database must be normalized and design in a standard form in order to avoid data duplication. This increases the speed of querying the database, easy to maintain and debug[1].

5.9.1. MySQL Workbench

MySQL Workbench is a unified visual tool which helps architects, developers, and database administrators (DBAs) to design a database or relational database in a bigger picture. MySQL Workbench provides data modelling, SQL development and comprehensive administration tools for server configuration, user administration and much more. MySQL Workbench is free and available on Windows, Linux and Mac OS. MySQL Workbench simplifies database design and maintenance, automates time-consuming and error-prone tasks, improves communication among DBA and developer teams, enables data architects to visualize requirements and resolve design issues before a major investment of time and resources is made, enables model-driven database design, which is the most efficient methodology for creating valid and well-performing databases while providing the flexibility to respond to evolving business requirements. MySQL model and schema validation utilities enforce best practice standards for data modelling. It enforce MySQL specific physical design standards so no mistakes are made when building new ER diagrams or generating physical MySQL databases.

5.9.2. Creating database dynamically

Since the software might be used by GPs, nurses or people which may have or even no computer literacy, it must be easy to install and use. Using the software on a new computer is required the database to be created for the first time. Creating the database using a C# scripting language will remove the need of using the MySQL Workbench or other software to create the database manually. It also enables to have a unique database with the same foreign, primary and index keys and the same field's types, length and values. The software firstly checks whether the database exists on the host computer. If there is no database found, the program displays a message by asking whether the user wants to create the database. It uses a series of commands to create the database dynamically.

[1] *Appendix C: Database entity-relationship diagram*

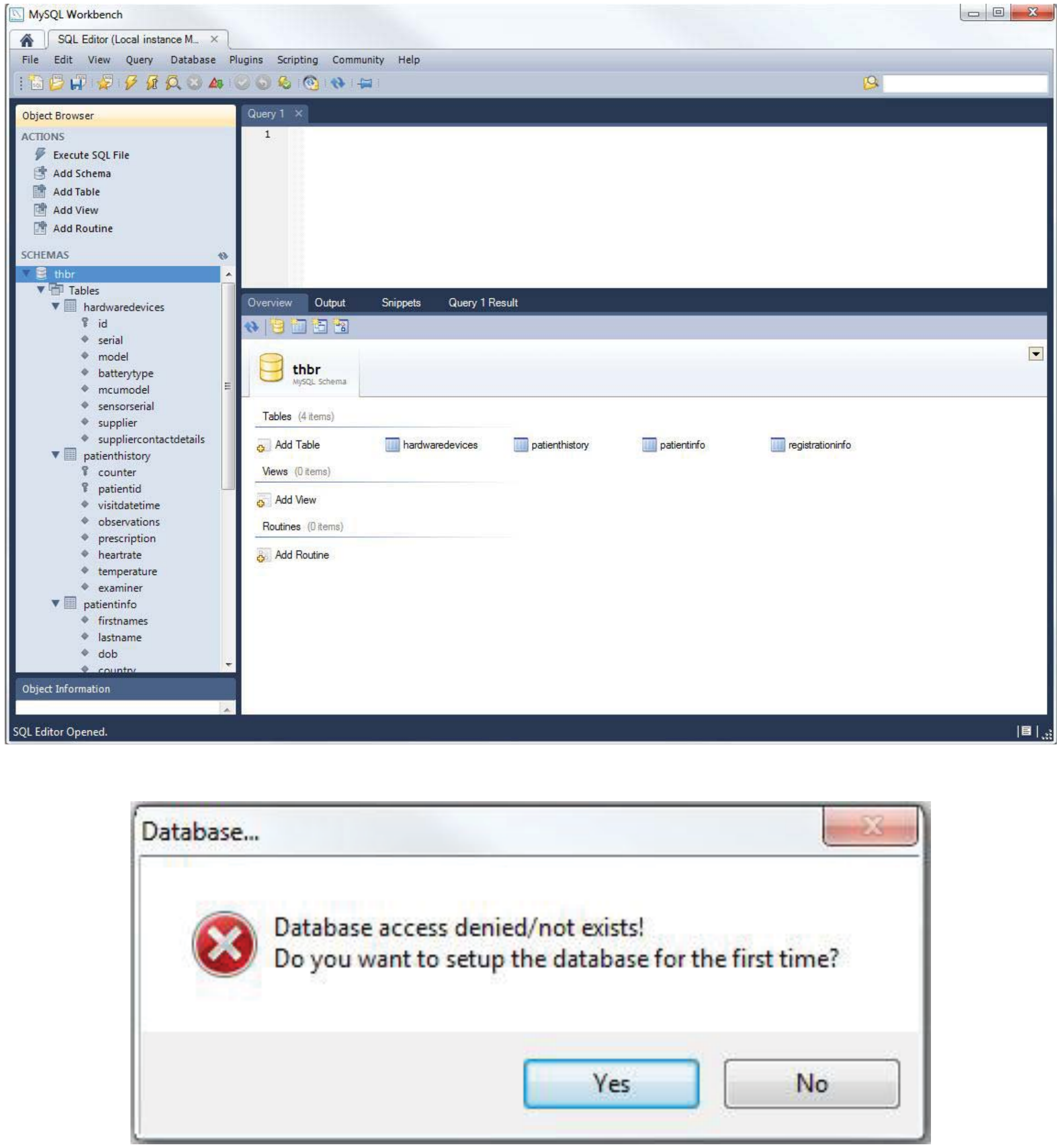

Fig 93: Creating database using MySQL Workbench (top) and T-HBR software (bottom)

The database can be created by the system administrator when the MySQL or Software system is required to be installed for the first time. On the other hand, creating the database dynamically (using a built-in script) allow users with minimum knowledge of software installation, to install the software system easily as well.

5.10. T-HBR software

The name of the software is chosen based on its functionalities. 'T' stands for Temperature and 'HBR' stands for Heart Beat Rate. Fig. 94 shows the start-up screen of the software.

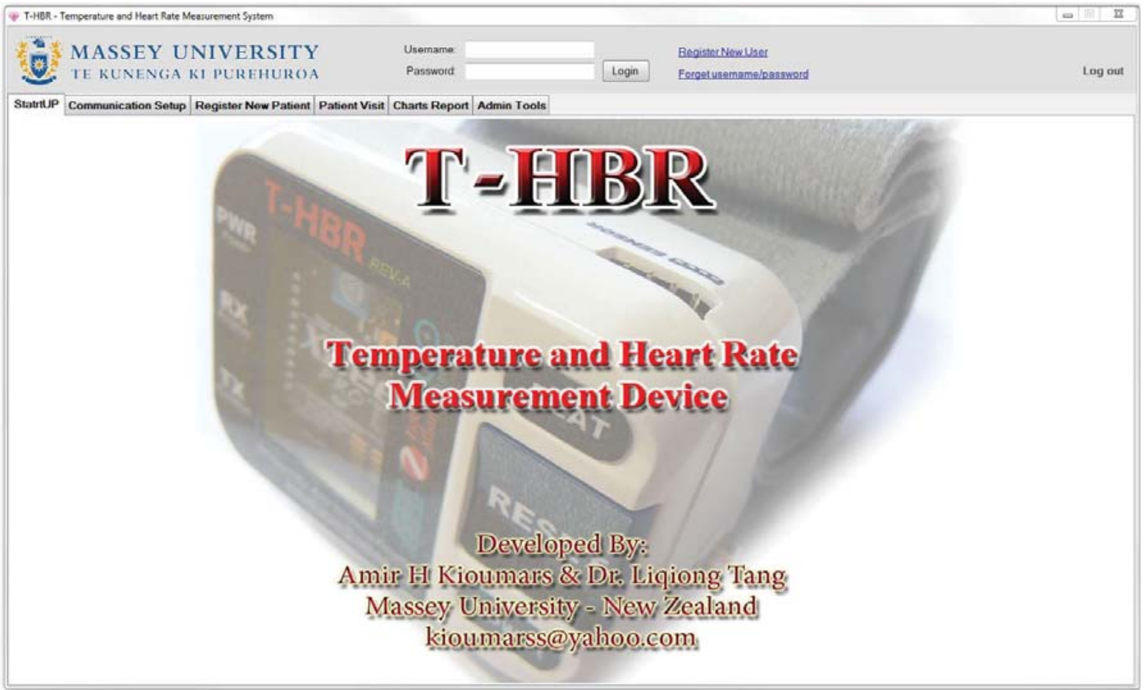

Fig 94: T-HBR software start-up screen

In order to access the system functions, each user must be logged in by his/her own unique username and password. A new user can be registered by clicking on the 'Register New User' button.

Access to the system functions is depends on the user restrictions. For example, if the user identifies as a GP, he/she can access all the system functions. But if the user identifies as a nurse, for example, it cannot issue the prescription and can only register a patient and see the data as read-only and they can just visit the patient and record the data.

Administrator on the other hand, has full access to the system functions such as backup, restore, encrypt and decrypt the database and modify the patient records. For security reason, GP's are not allowed to change anything such as patient records, previous prescriptions and so on. It will make GPs responsible for any observations they are made and any prescriptions they are issued. This enforce GPs to have a good observation because once they submit the data, they will not be able to change.

5.10.1. Register new user

Fig. 95 shows the user registration form:

Fig 95: Registration form

All the fields are required to be filled. The user interface (UI) guides the user to fill out the form. For example, if the user types a short password (2 characters long), the back colour of the password field becomes red, indicating that it is not a good choice (short password length). Yellow colour indicates that it is a moderate choice and green (for 8 characters long or more) shows a good password length. Also all the field's values are validated by the software. If the user dose not inserts the right value, the system will not allow him/her to be registered. In addition, the database queries the 'user registration table' to make sure the user has not been registered previously. The 'Identification' number is referred to the GPs unique National Health Identification number (NHID).

5.10.2. Retrieve login information

It is always possible that a user loses or forgets his/her 'username' and/or 'password'. The system allows the user to send a request to retrieve his/her login information:

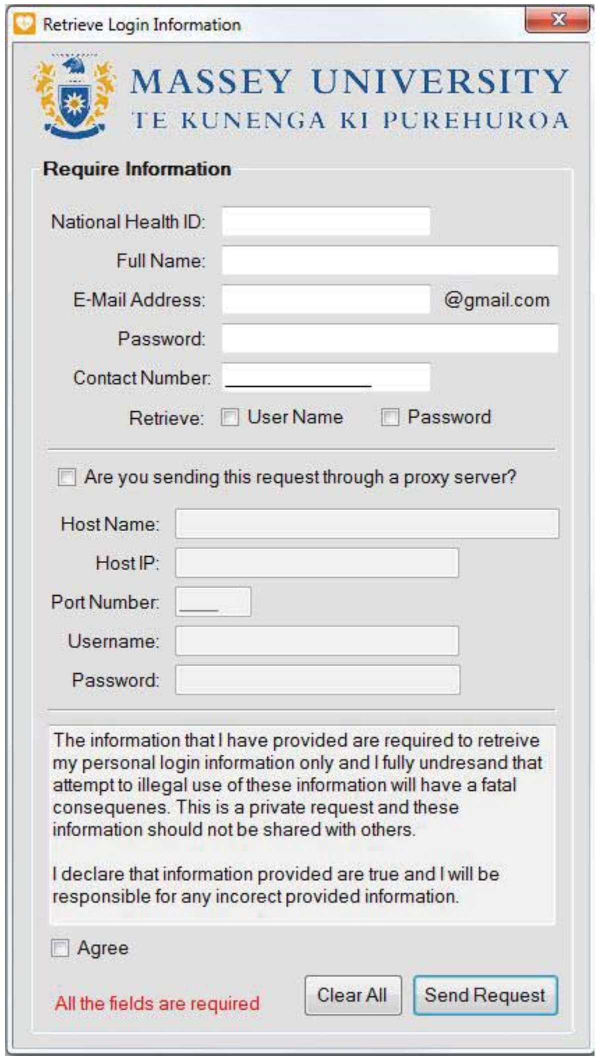

Fig 96: Retrieve login information form

All the fields are required to be filled. The top section of the form contains the user general information and two options which allow the user to indicate which login information needs to be retrieved. The middle section of the form is used if the software system requires an e-mail to be sent through proxy. The last section is an acknowledgement which must be accepted to send the request. This acknowledgement informs the user about the risk of trying to retrieve someone else's login information, for example. All the fields are validated before sending the request Fig. 97 shows a sample request to the administrator and the email received by him/her in order to retrieve the login information:

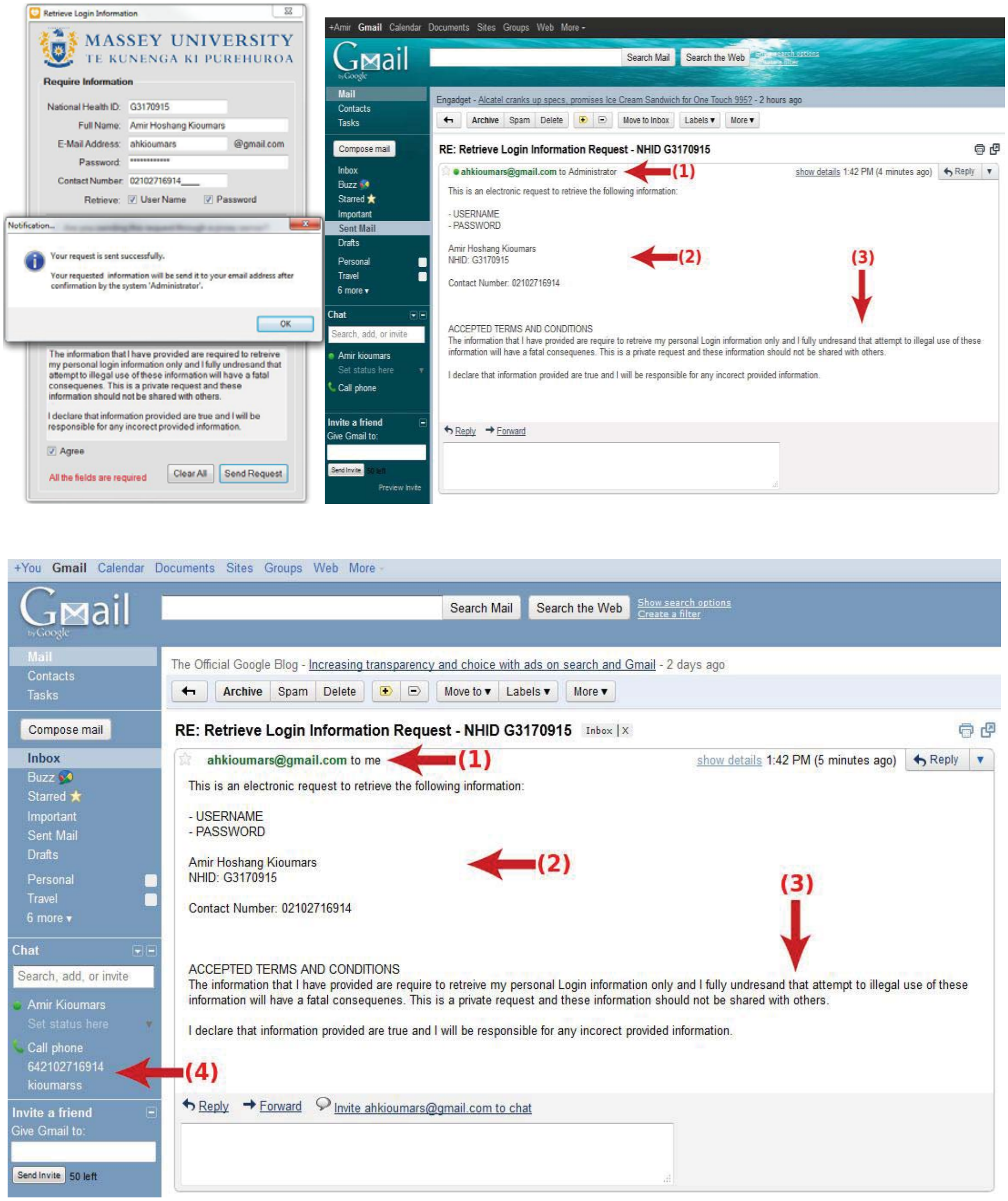

Fig 97: Request, send and receive email

(1) E-mail sender/receiver

(2) E-mail body indicating the requested information, electronics signature and contact details

(3) Accepted terms and condition as an evidence attached to the e-mail

(4) Sender contact number

The administrator may wish to send the information by e-mail or contact the person by phone.

5.10.3. Gmail SMTP server

Almost all organizations have their own e-mail server. This research provides a template for using a SMTP server to send and receive e-mails and it can be replaced by any SMTP server (for example hospital SMTP server) with its unique parameters.

Gmail provides a free sending mail transfer protocol (SMTP). There are some paid options around, but Gmail is one of the best choices for a robust free service. It is only requires a Gmail account to be setup. The T-HBR software uses Gmail mail service. This has a great advantage which allows the all incoming and outgoing messages to be stored within the Gmail mail server. Gmail accounts are free with unlimited storage space. Table 19 shows the required information for using the Gmail SMTP server within any programming languages such as C#:

Incoming Mail (POP3) Server Requires SSL:	your.isps.pop3.server.com Use SSL: No Port: 110
Outgoing Mail (SMTP) Server Requires TLS:	smtp.gmail.com (use authentication) Use Authentication: Yes Use STARTTLS: Yes (some clients call this SSL) Port: 465 or 587
Account Name:	Gmail username (including '@gmail.com')
Email Address:	original ISP address (username@yahoo.com)
Password:	Gmail password

Table 19: Gmail SMTP server configurations[1]

According to the Gmail official website, Gmail makes email easy and efficient. Gmail accounts have the following benefits which are free to use:

- Less spam. Gmail blocks spam before it gets to the inbox
- Search. Search instantly within Gmail to find the exact desired message
- Conversation view. Messages are grouped with the relevant responses so the user can always see messages in context
- Built-in chat. Gmail enables users to talk face-to-face with voice and video chat
- On the go. Gmail account can be accessed from the phone regardless of the device type
- Labels, filters, and stars. It uses labels to stay organized. Each email can have several labels, so the users are not forced to choose one particular folder for messages
- Priority Inbox. Gmail automatically separates important emails from everything else and focuses on what really matters

[1] *The Gmail account address setup for this research: Username: THBR.MAIL.SERVICE – Password: masseyuniversity*

- Secure. Similar to the bank websites, Gmail uses HTTPS encryption to keep the user's e-mail secure

5.10.4. Gmail to SMS

"Short Message Service (SMS) is a text messaging service component of phone, web, or mobile communication systems, using standardized communications protocols that allow the exchange of short text messages between fixed line or mobile phone devices." (Wikipedia, retrieved 2011)
The SMS gateway is software that allows SMS messages to be sent and received to and from the mobile network. The SMS gateway forwards messages to the mobile network either with a GSM modem attached to the PC or software connects directly to the SMS centre of the mobile service provider over the Internet.
In the case of the SMS gateway, it is important to select one that will be able to handle even greater numbers of messages if it is required. Such an SMS gateway is 'Ozeki NG SMS Gateway[1]'. It can be installed to the corporate computer and it will gives access to the SMS centres of mobile service providers. It is able to add SMS functionality to corporate applications like Gmail. It is the proper SMS gateway both for smaller companies and for those who operate with greater numbers of SMS messages due to its outstanding performance. Fig. 98 shows the system architecture consisting Gmail and Ozeki NG SMS Gateway:

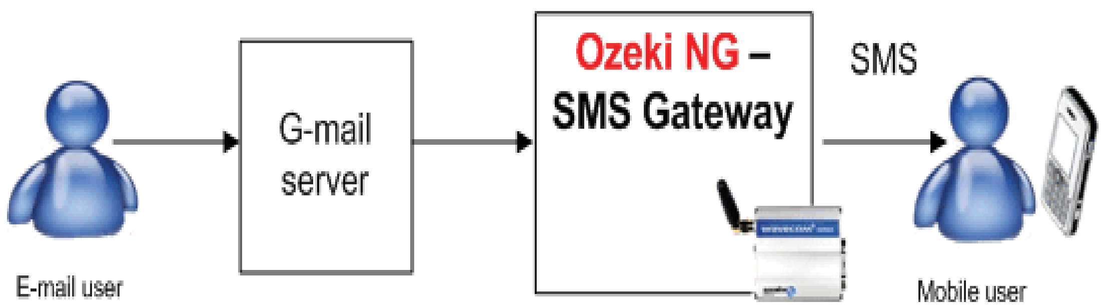

Fig 98: Gmail and Ozeki NG SMS gateway system architecture

Installing and configuring the Ozeki SMS gateway software is tricky. Gmail hides these complexities by having its own mail to SMS gateway. Therefore the users do not need to use any additional software such as Ozeki. It can be done by entering the mobile number in 'forwarding message' option within the Gmail configuration tab. In addition, the Gmail's e-mail can be forwarded to any other e-mail accounts or mobile devices that have been setup within this tab (for example next of kin of a patient or his family members).

[1] *OZEKI NG SMS Gateway is a high capacity SMS server that is very popular among ISV/OEM, Enterprise, and Community Users. It is recognized for its superior ease of use, performance and reliability. Reference: www.ozekisms.com*

5.10.5. Communication settings

This allows communication with the remote device, queries and changes settings. Most of the existing software cannot identify a new hardware which is attached to the serial port while they are running. They require ‘hard reset’ (close and open the program) to identify the new hardware. This will result in loss of current configuration settings. The T-HBR software does not require this. By clicking on the ‘Refresh’ button, the program saves the current configurations, reset itself internally and restores with the stored configuration settings. At the same time, the software checks the serial ports for any changes and lists them under ‘Available COM Ports/Settings’. Having the COM port[1] number such as COM1 or COM2 will not help much by itself. Therefore the software extracts the hardware information on each port and displays them to help users to select the right ‘COM’ port. Fig. 99 shows the ‘Communication Setup’ tab:

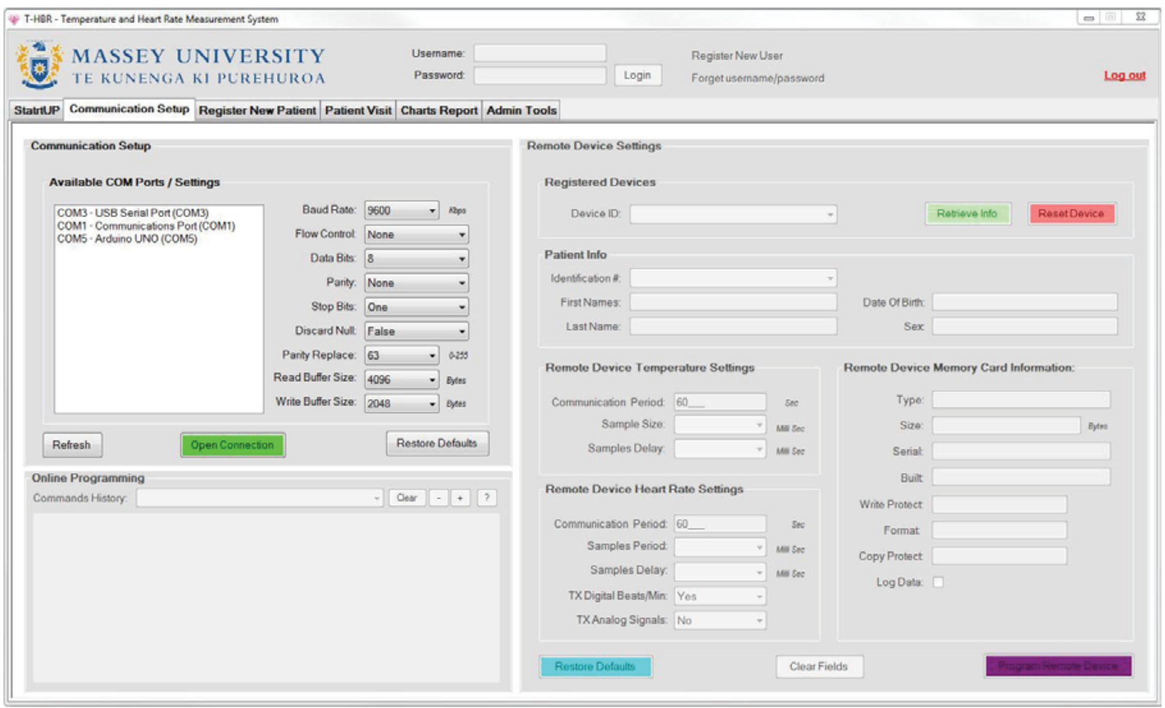

Fig 99: Communication setup

Normally, COM1 is reserved by Windows operating system. When connecting the USB dongle or explorer which enables the XBee module to be connected to the PC, it appears as a ‘Communication Port’ and is normally installed on COM5, 7 or 9. These will differ, depending on the number of devices connected to the serial ports.

[1] *COM stands for communication and COM port stands for communication port*

5.10.5.1. Setting-up a new hardware

By opening the desire port, the serial communication will start, the 'Remote Device Settings' options are enabled and 'Device ID' list will be manipulated by the registered hardware IDs which are read from the database:

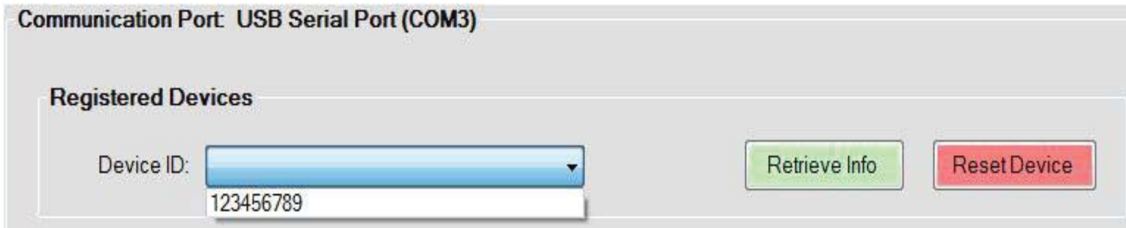

Fig 100: List of the registered hardware

Assume a hardware device is brand new and it is not assigned to any patient yet. It only has its own unique identification number (123456789). This number cannot be changed and it is pre-programmed (hard coded) by the manufacturer.

By querying the device, the system tries to match the remote device identification number (ID) with the registered device within the database. If it is a valid ID, then the software tries to read the EEPROM values. As the device is brand new and not assigned to anyone yet, the following message will be displayed, informing the operator to take an appropriate action.

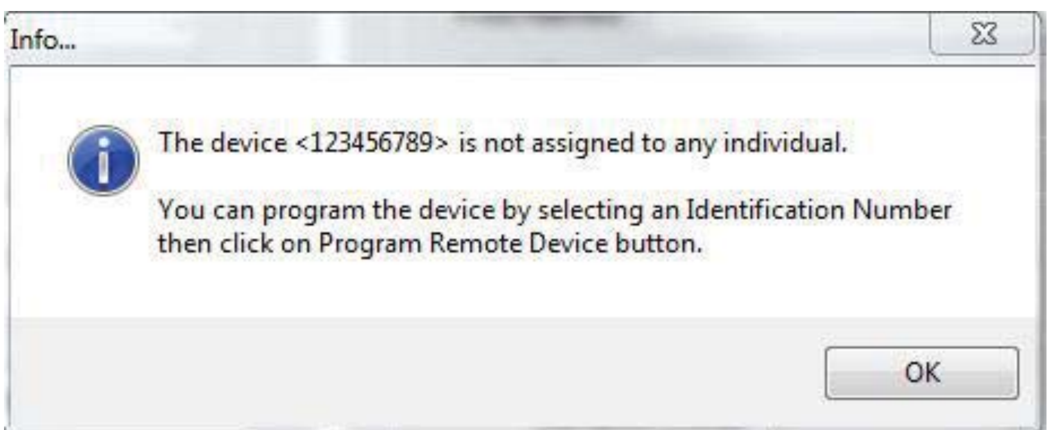

Fig 101: Querying the new device

By selecting a patient from 'Identification #' list, all the primary information about the selected patient will be retrieved from the database and manipulated in the 'Patient Info' fields.

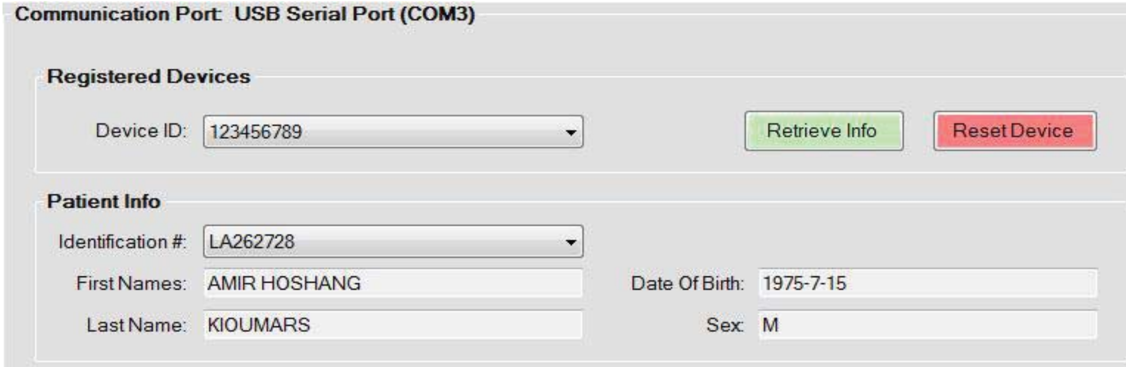

Fig 102: Selecting a patient

The next stage is to define the temperature and heart rate parameters. Also, querying the hardware shows if there is any memory card installed on the remote device. Therefore, it can be decided whether data needs to be logged on the memory card. The final step is to upload the data to the remote device by clicking on the 'Program Remote Device' button:

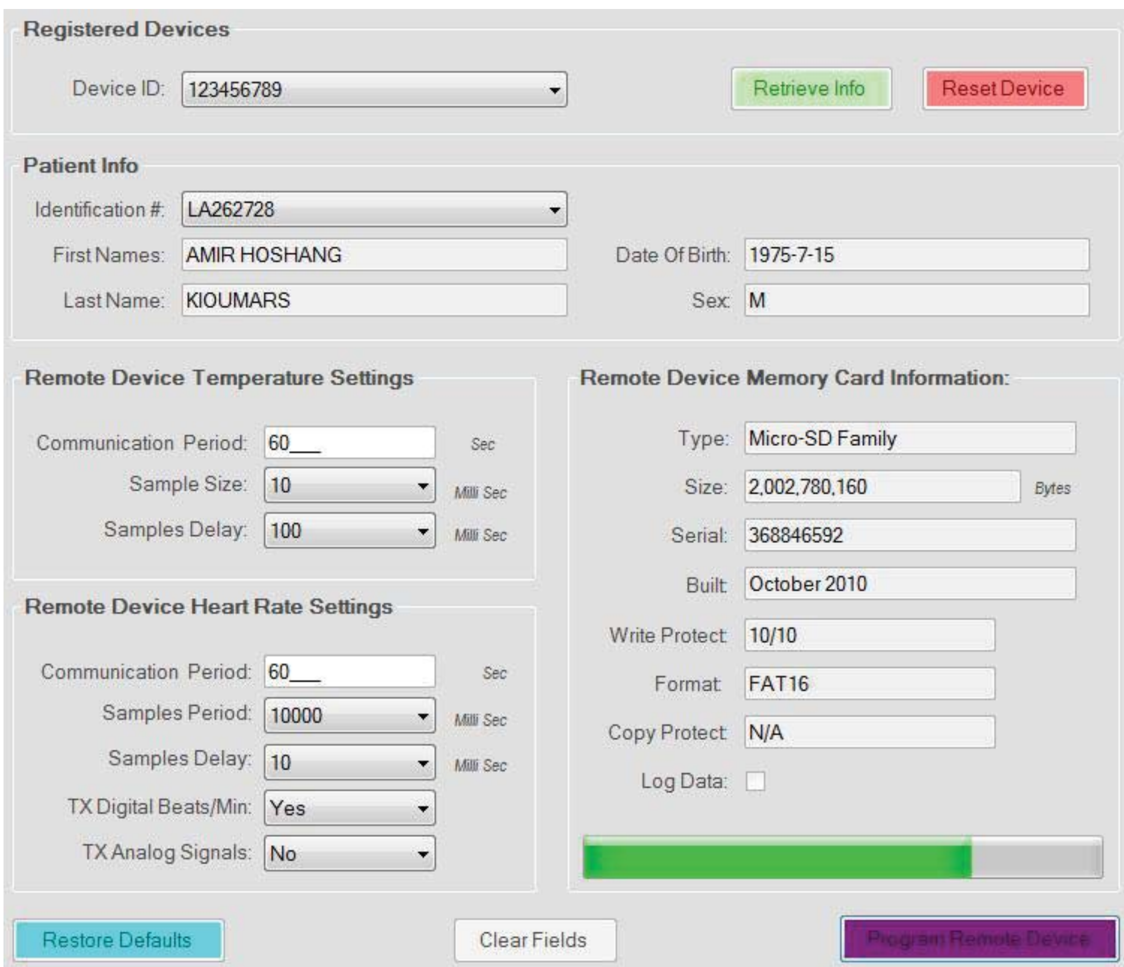

Fig 103: Uploading information to the remote device

5.10.5.2. Command line programming

This option allows the user to program the desired field on the remote device. It does not require the whole packet to be transmitted. Instead, it only transfers the desired value, resulting in faster updating of the remote device. This is a single line programming mode and sending simultaneous commands is not permitted. A correct command will be added to the command history automatically in order to avoid typing the same command if it is needed[1]. Any unrecognised command will generate an error.

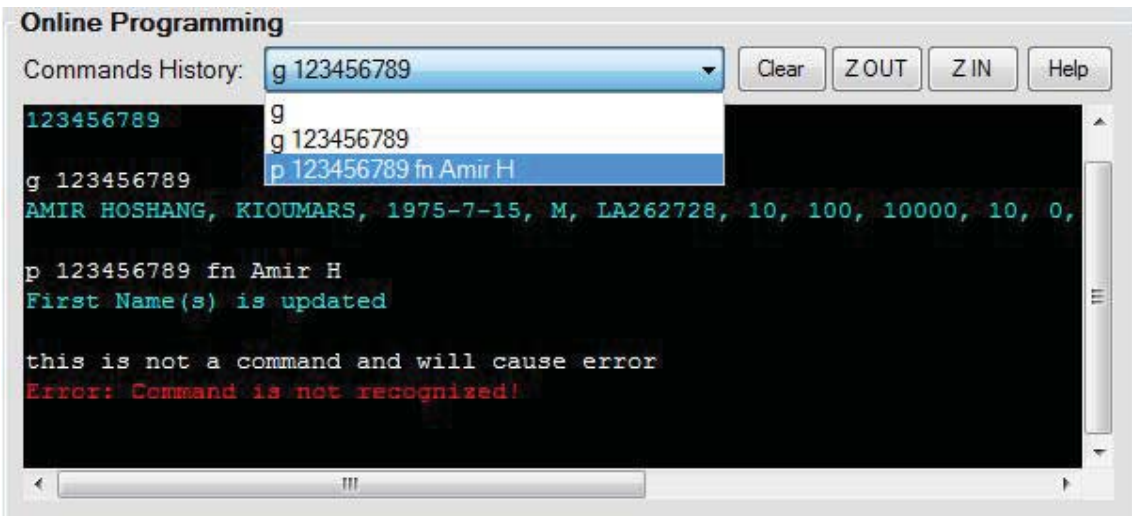

Fig 104: Sample online programing the remote device

[1] *Section 5.4.3. Micro-controller commands*

5.10.6. Registering a new patient

This option allows a new patient to be registered into the system. Fig. 105 shows the registration form and the required field in order to register a patient.

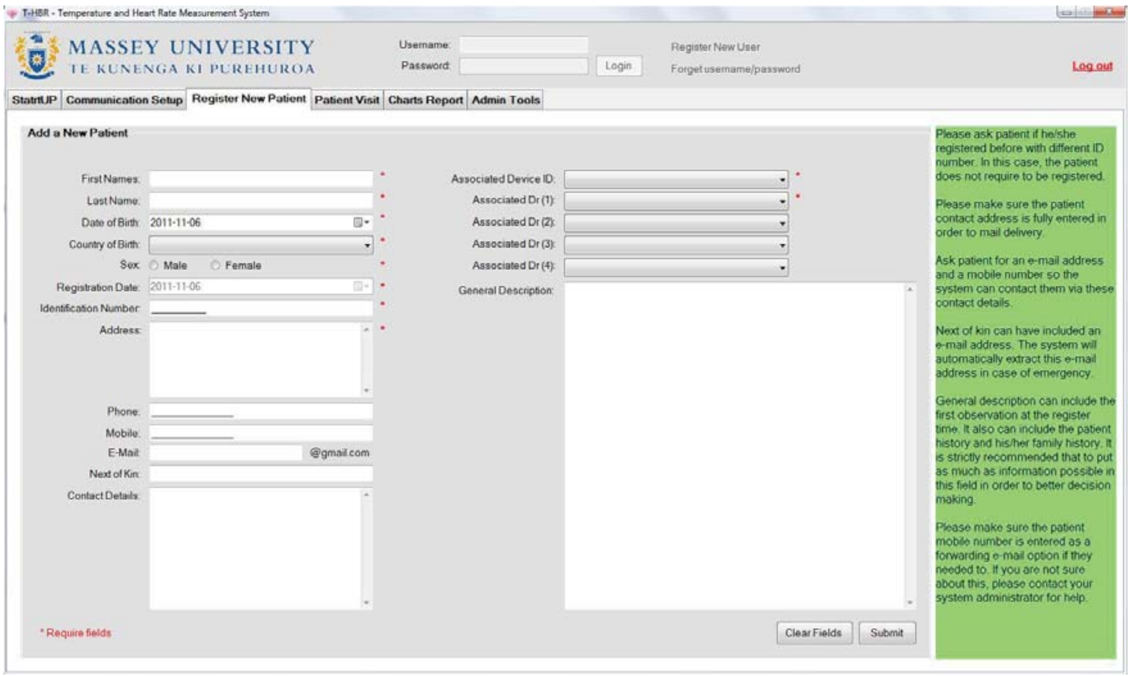

Fig 105: Register new patient form

It is recommended to do the following steps when registering a new patient:

- Ask the patient if he/she was registered before with a different ID number. In this case, the patient does not require to be registered. This will helps to prevent data duplications
- Make sure the patient's contact address is fully entered in case of any mail delivery.
- Include next of kin's e-mail address in his/her contact details. The system will automatically extract this e-mail address from the information and can send an e-mail in case of emergency
- General description can include the first observation at the registration time. It also can include the patient and his/her family history. It is strictly recommended to put as much as information possible in order to help GPs for better decision making
- Make sure the patient mobile number is entered as a forwarding e-mail option if they needed to receive their e-mails on their mobile phone. This will be beneficial if there is no access to the Internet (patient is in travel for example)

5.10.7. Visiting system

One of the major functions of the system is 'Patient Visit'. This allows a GP to:

- Visit a patient remotely or at office
- Access the patient's history information and/or update them
- Get the patient's temperature and heart rate remotely or at the office
- Record the observations
- Issue a prescription
- Send the required information to the patient, other GPs and the patient's next of kin by e-mail and/or text message
- Submit the information to the database

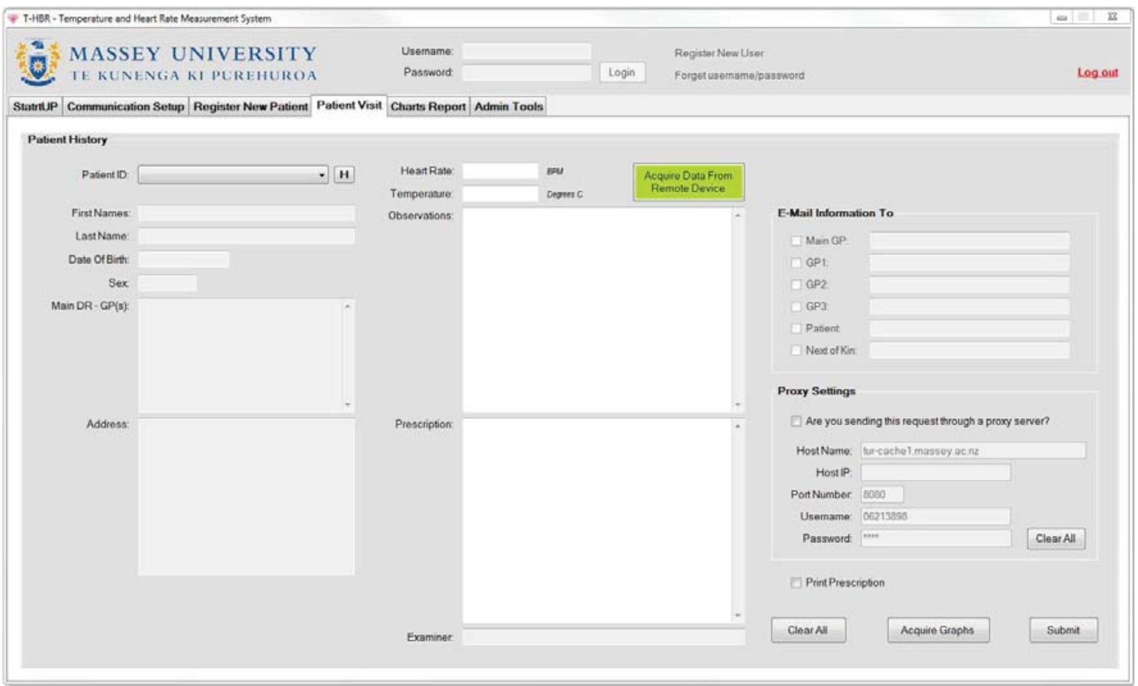

Fig 106: Patient visit form

5.10.7.1. Visiting a patient

It is important to have a clear observation and issue the right prescription to the right patient. Therefore, by selecting a patient from 'Patient ID' list, the patient's information is displayed on the left side of the form, indicating who the GP is visiting. The GP might ask some security questions based on these fields for further confirmation.

The middle part of the form is critical. Heart rate and temperature values can be either inserted manually or acquired from the remote device wirelessly. After submitting the information to the database, it cannot be altered but can only be modified by the system administrator. Examiner information (name and ID of the person that already logged in to the system and visiting the patient); date and time of the visit are attached to the data automatically before submitting to the database. This will reduce the risk of any denial and there will be a responsible person for any visit.

GPs are allowed to send the prescription to other GPs, patient and patient's next of keen. This information will automatically be sent to their mobile device if their number is registered as a secondary forwarding address. In addition, GPs may wish to attach a heart rate and temperature graph to the e-mail. Therefore, in order to reduce the size of data and have faster delivery, all this information (include a PDF file of prescription) is compressed as a ZIP file and attached to the e-mail. The prescription is issued as a PDF file so no one will be able to alter its contents. Fig. 107 shows a sample visit by 'Dr Mark Mories' with health identification number 'NZHID123'. He also wishes to send the prescription to his patient e-mail address though a proxy and print his prescription:

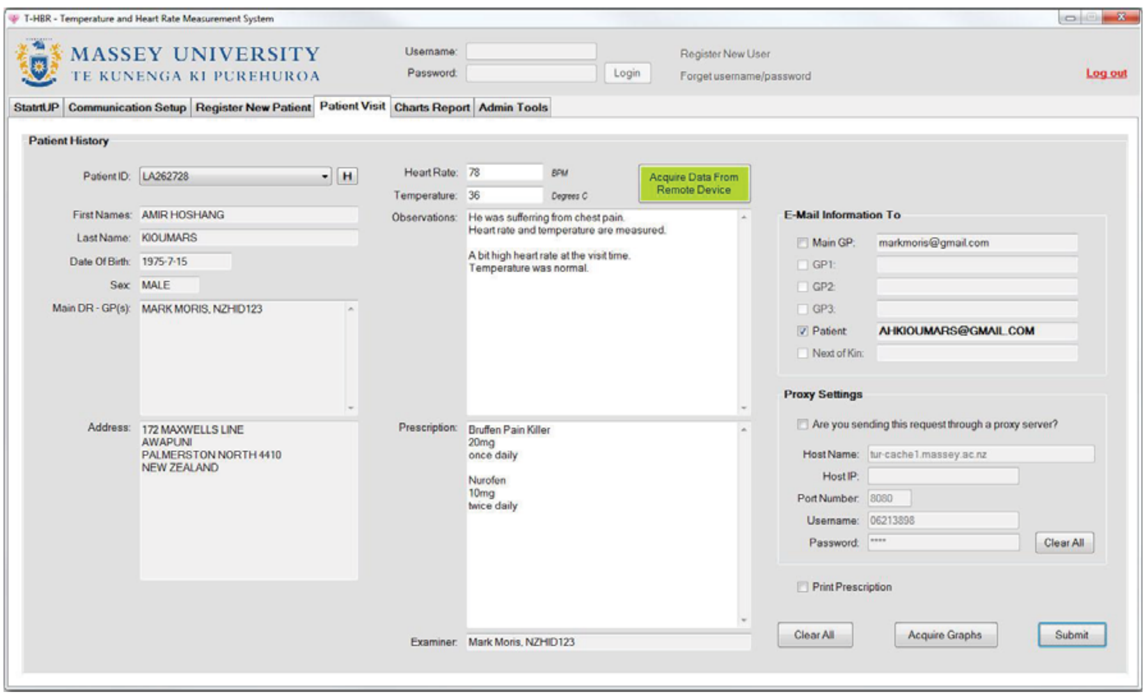

Fig 107: Sample patient visit

Data compression is particularly useful in communications because it enables devices to transmit or store the same amount of data in fewer bits. Microsoft Windows supports standard ZIP file compression techniques. Therefore no additional libraries are required to be installed.

5.10.7.2. Patient history and previous visits

It is possible to have access to the patient history and visits in order to make a better decision by GPs. This can be done by clicking the 'H' button next to the 'Patient ID' list. After selecting a patient, by clicking on this button, the patient history is displayed as shown in Fig. 108:

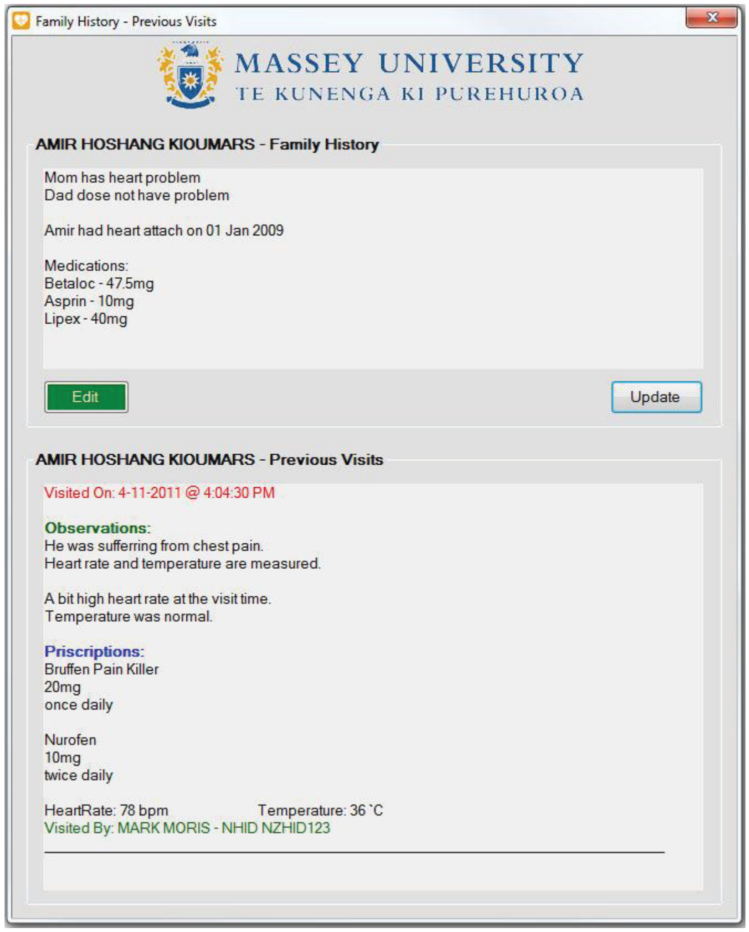

Fig 108: Patient history and previous visits

GPs are allowed to update the patient history if they required adding more details but they are not allowed to change information from any of previous visits.

5.10.8. Charts reports

Charts are often used to ease understanding of large quantities of data and the relationships between parts of the data. Charts can usually be read more quickly than the raw data that they are produced from. A line chart or line graph is a type of graph, which displays information as a series of data points connected by straight line segments. It is a basic type of chart common in many fields. A line chart is often used to visualize a trend in data over intervals of time (a time series). Thus the line is often drawn chronologically. ‘Chart reports’ function allows visualizing the patient heart rate and temperature over time.

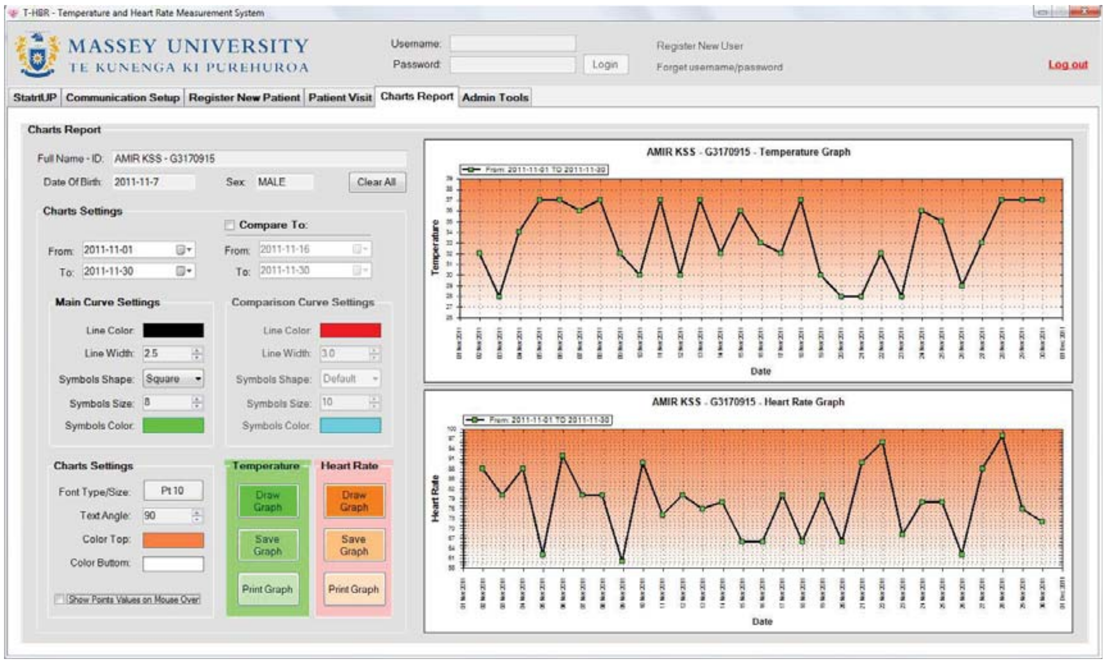

Fig 109: Temperature and heart rate graphs

It also enables GPs to compare a series data over two distinct period of time on the same graphs.

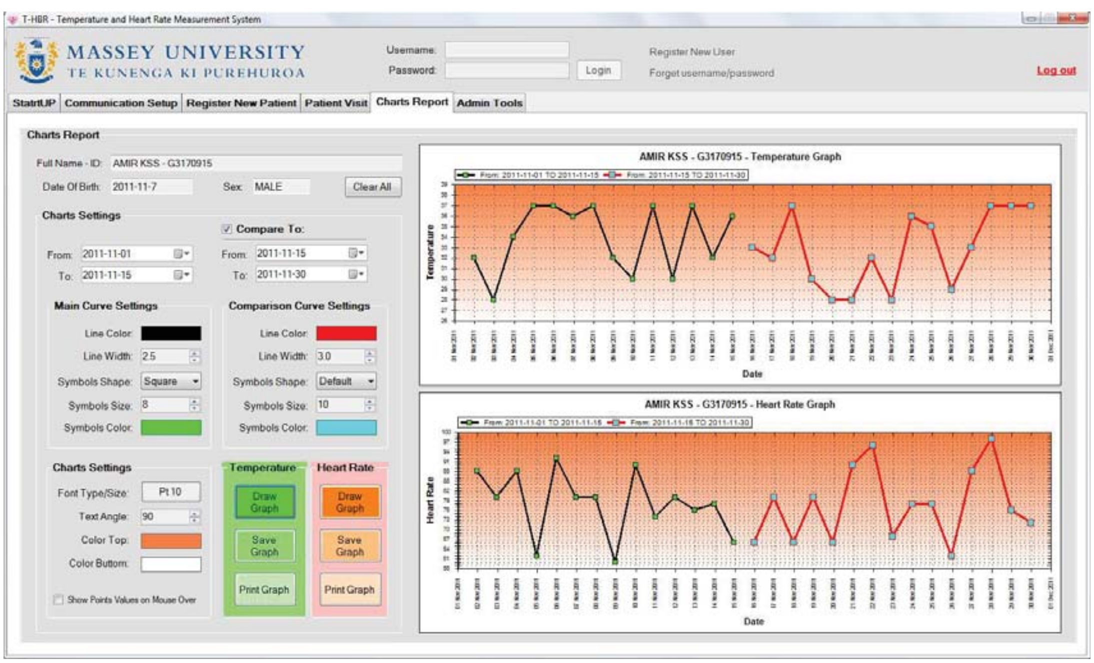

Fig 110: Temperature and heart rate graphs comparison

'Chart Reports' tab has the following functionalities:

- Mouse over the graphs which will maximize the size of the graph in order to make it easy to read on the screen
- Show the value of each point by moving the mouse over it
- Change the graphs fonts, line colours and width
- Change the points colour, size and shape
- Change the background colour (either plain or a gradient)
- Change the angle of texts
- Save a desired graph as a high resolution PNG[1] picture (300 DPI[2]) which enables the picture to be resized without losing much quality
- Print a graph

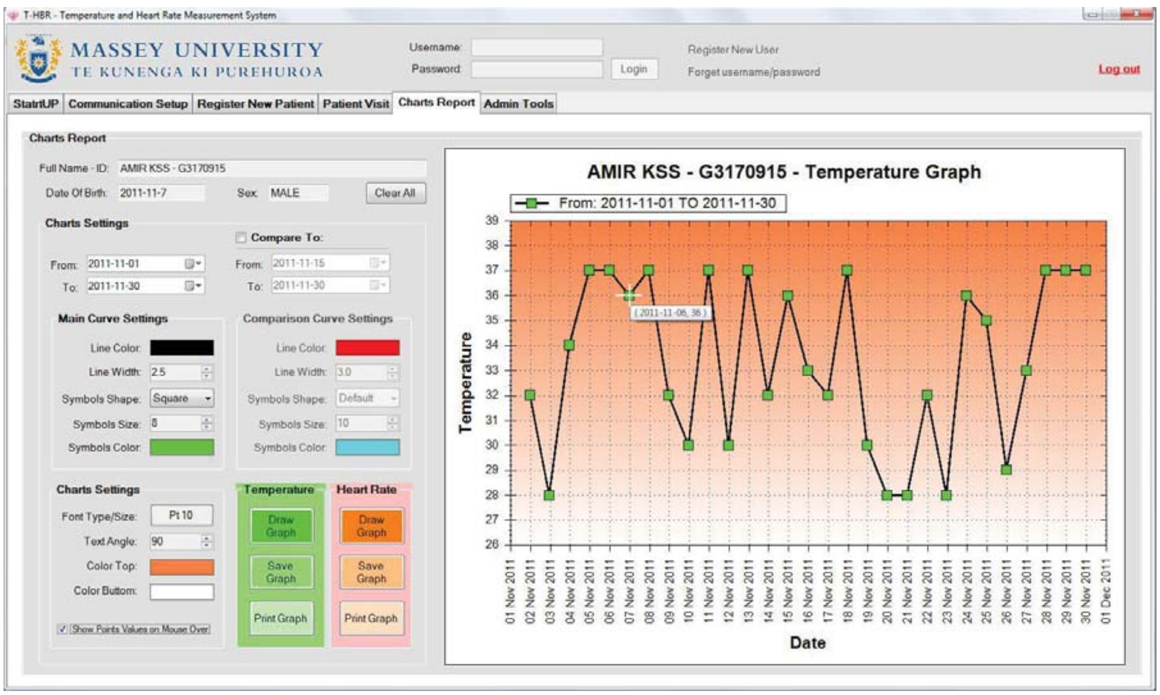

Fig 111: Activating show points values on mouse over

Saved graphs and 'PDF' file of prescription are stored under the same folder. This folder contains a copy of a prescription and charts. If it is required to be sent by e-mail, this folder will be compressed and attached as a single document to the e-mail.

[1] *"Portable Network Graphics (PNG): is a bitmapped image format that employs lossless data compression. PNG was created to improve upon and replace GIF (Graphics Interchange Format) as an image-file format". Reference: Wikipedia*

[2] *"Dots per inch (DPI): is a measure of spatial printing or video dot density". Reference: Wikipedia*

5.10.9. Admin tools

'Admin tools' allows administrator to:

- Register a new hardware device
- Backup and restore the database
- Have access to the central database and add, delete or update the information

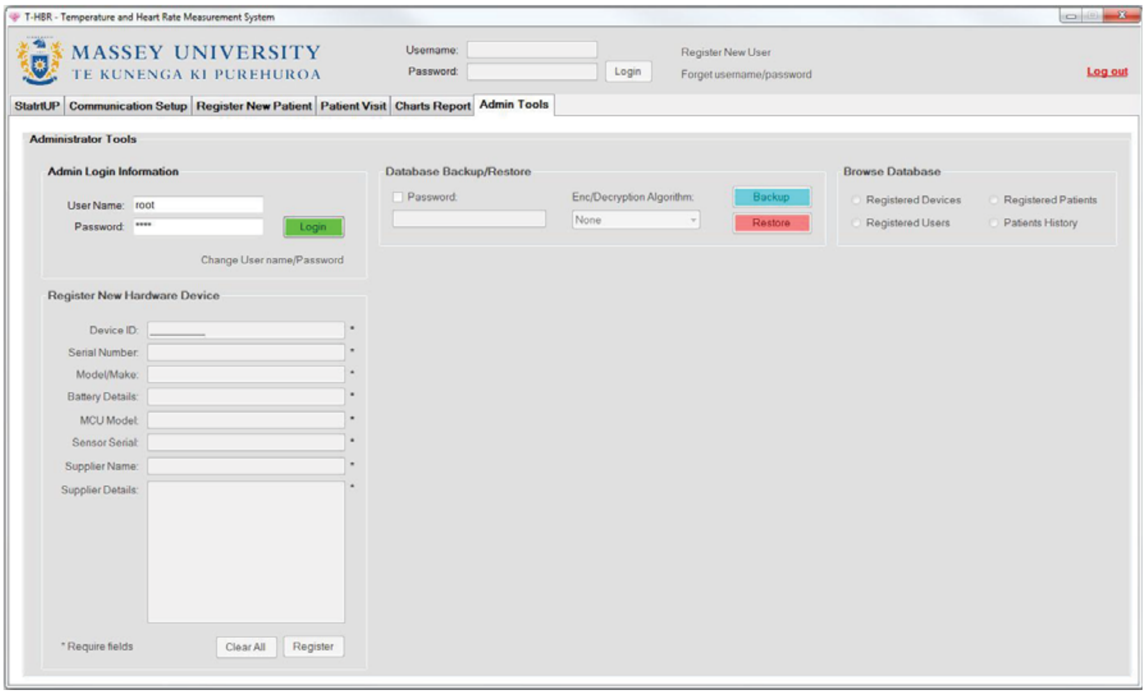

Fig 112: Admin tools

5.10.9.1. Admin login information

This allows the administrator to login to the system with full access to all the functionalities. In addition, the administrator can change his/her login information.

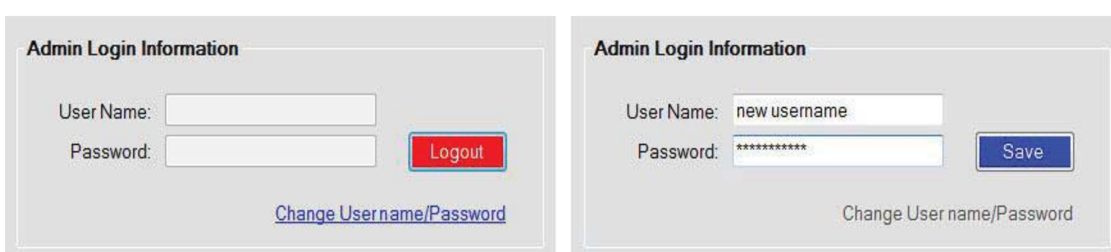

Fig 113: Admin: login (left) - change username/password (right)

5.10.9.2. Register a new hardware device

Each hardware device has its own unique specifications such as:

- Device identification number (ID)
- Serial number (SN)
- Sensor serial number (SSN)

This information is attached to the hardware device and is un-changeable. Each hardware device must be registered by the administrator before use. For security purposes (losing the device, faults, maintenance and etc.), all the information about the hardware device is required to be entered into the system and stored into the database. Fig. 112 (left side of the slide) shows the 'Register New Hardware Device' panel. All the fields parse though a validator to make sure hardware information is valid and the device has not previously been registered. The 'Device ID' fields is very critical and it must be exactly identical as the hardware device otherwise it will not be recognized by the T-HBR software.

5.10.9.3. Backup and restore the database

One of the key functionalities of the administrator is to maintain the database. T-HBR enables the admin user to backup and/or restore the database. It also can encrypt the database backup in order to increase the security. The most common way to back-up a MySQL database is by using 'MySqlDump[1]' and 'MySQL Administrator[2]' files which comes with the MySQL package. MySQL Administrator is good for developers, but when it comes to client or end-user, they just need to click a button to backup. Using MySQL Administrator as a backup tool is not a suitable solution for client or end-user. On the other hand, MySqlDump is another tool that can customize within the code to meet the specific situation. However, MySqlDump has compatible problems while handling unicode[3] characters, for example Korean, Japanese, Chinese and Russian characters. The data will be corrupted during the encoding between MySQL database and MySqlDump. Therefore, the T-HBR software uses its own backup/restore tool. It does not rely on two small programs, MySqlDump.exe and MySql.exe to perform the backup and restore task. Besides, it has better control over the output result. The encryption can be done using one of the following algorithms:

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[1] *'mysqldump' can be used to dump a database or a collection of databases for backup or for transferring the data to another SQL server. Reference: MySQL documentation*

[2] *'MySQL Administrator' is a program for performing administrative operations, such as configuring, monitoring and starting and stopping a MySQL server, managing users and connections, performing backups, and a number of other administrative tasks. Reference: MySQL documentation*

[3] *"Unicode is a computing industry standard for the consistent encoding, representation and handling of text expressed in most of the world's writing systems". Reference: Wikipedia*

- Secure Hash Algorithm (SHA): 160-bit hash function
- SHA256: Hash function with 32-byte (256 bits) words
- SHA384: Truncated version of SHA512
- SHA512: Hash function with 64-byte (512 bits) words
- MD5: Produces a 128-bit (16-byte) hash value. MD5 has been employed in a wide variety of security applications and is also commonly used to check data integrity[1]
- Data Encryption Standard (DES): It is a block cipher that uses shared secret encryption
- RC2: RC2 is a 64-bit block cipher with a variable size key
- Rijndael: It is a new generation symmetric block cipher that supports key sizes of 128, 192 and 256 bits, with data handled in 128-bit blocks
- Tripple Data Encryption Algorithm (TripleDES): It is a block cipher, which applies the DES cipher algorithm three times to each data block
- BlowFish: Blowfish has a 64-bit block size and a variable key length from 1 to 448 bits
- Twofish: Symmetric 128-bits block cipher and key size up to 256 bits

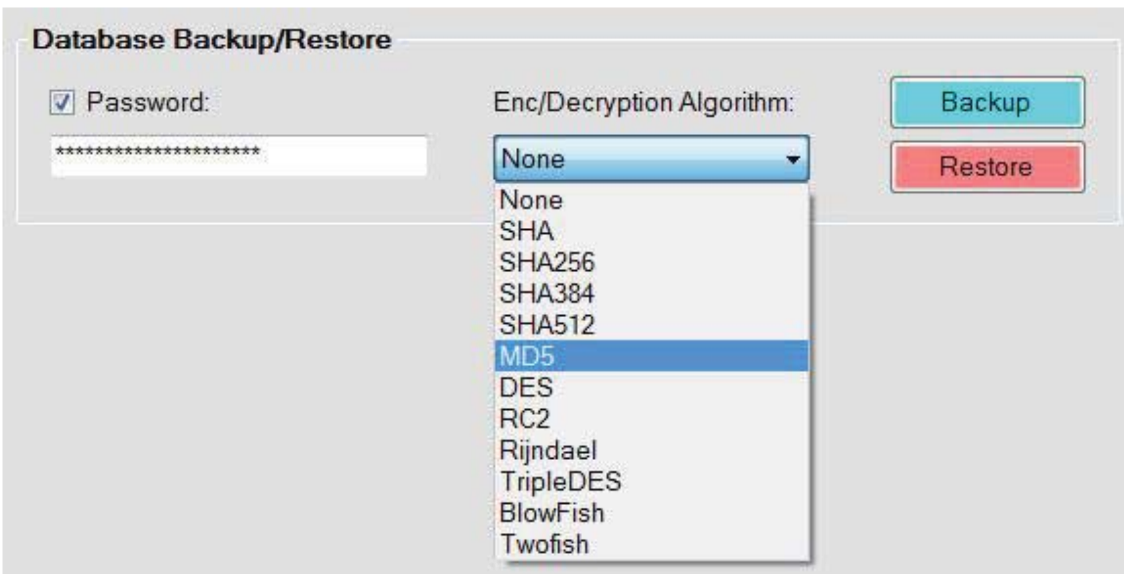

Fig 114: Admin backup/restore panel

The encrypted backup file can have a password to further protection. Combination of password and encryption algorithm makes the backup more secure. In order to restore the database safely and avoid any conflict with the existing database, the following steps are taken by T-HBR restore function:

[1] *Reference: www.microsoft.com*

- Create a clean backup from the existing database using a password and an encryption algorithm. The password is generated using a random text generator (a password with 10 characters length) and an encryption algorithm is randomly selected
- Restore the desired database
- If the restore operation is successful, then the previous backup will be deleted. Otherwise the previous backup will be restored (roll-back the changes). This avoids inconstancy in database

All the above operations are hidden to users and reduce the user workloads. Instead they just need to do the backup and/or restore by a simple click. Backup and restore must have exactly the same ‘password’ and ‘encryption algorithm’.

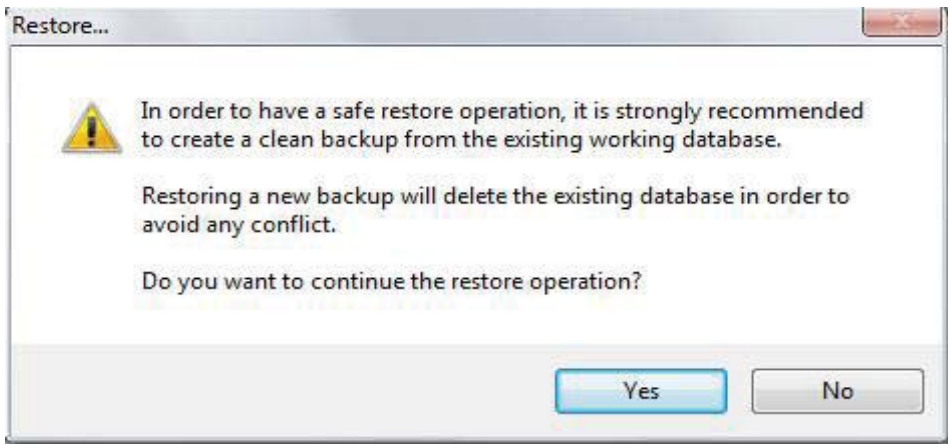

Fig 115: Restore warning message

5.11. Software code metrics

Software code metrics[1] are the set of software measures that provide better insight into the software code. They allow developers to understand which types and/or methods should be reworked or more thoroughly tested. Programmers can identify potential risks, understand the current state of a project and track progress during software development. The following software metrics can be calculated using Microsoft Visual Studio[2]:

- Maintainability index
- Cyclomatic complexity
- Depth of inheritance
- Class coupling
- Lines of code

5.11.1. Maintainability index

This is an index value between 0 and 100 that represents the relative ease of maintaining the code. A high value means better maintainability. Visual Studio uses colour coded ratings to quickly identify trouble spots within the code. These ratings are classified as follows[3]:

5.11.2. Cyclomatic complexity

This (CYC) measures the structural complexity of the code. It is created by calculating the number of different code paths in the flow of the program. A program that has complex control flow will require more tests to achieve good code coverage and will be less maintainable.

5.11.3. Depth of inheritance

Depth of inheritance (DIT) indicates the number of class definitions that extend to the root of the class hierarchy. The deeper the hierarchy, the more difficult it might be to understand where particular methods and fields are defined or/and redefined. This is a key concept in the object model and must be carefully used. A class situated too deeply in the inheritance tree will be relatively complex to develop, test and maintain. A compromise between the high performance power provided by inheritance and the complexity which increases with the depth must be

[1] *Appendix C: Software metrics analysis results*

[2] *"Microsoft Visual Studio is a powerful IDE that ensures quality code throughout the entire application lifecycle, from design to deployment". Reference: www.microsoft.com/visualstudio*

[3] *Reference: www.microsoft.com/visualstudio*

found. A value of between 0 and 4 respects this compromise. A value greater than 4 would compromise encapsulation and increase complexity[1].

5.11.4. Class coupling

This (CC) measures the coupling to unique classes through the following items:

- Parameters, local variables, return types and method calls
- Generic or template instantiations
- Base classes and interface implementations
- Fields defined on external types and attribute decoration

Good software design dictates that types and methods should have high cohesion and low coupling. High coupling indicates a design that is difficult to reuse and maintain because of its many interdependencies on other types. The class coupling value between 10 and 20 is the most efficient[2].

5.11.5. Lines of code

Line of code (LOC) indicates the approximate number of lines within the code. A very high count might indicate that a type or method is trying to do too much work and should be split up. It might also indicate that the type or method might be hard to maintain.

5.11.6. Software testing

Software testing is an investigation conducted to provide developers with information about the quality of the product or service under test. Software testing can be stated as the process of validating and verifying that a software program/application/product. Pex and Moles[3] are isolated and the white box unit testing for .NET is developed by Microsoft .NET research group. Pex automatically generates test suites with high code coverage and Moles allows any .NET method with a delegate to be replaced[4]. Software memory profiling, sample profiling and instrumentation profiling are also measured as a part of the software testing[5].

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[1] *Reference: support.objecteering.com*

[2] *Reference: www.microsoft.com/visualstudio*

[3] *Pex and Moles: research.microsoft.com*

[4] *T-HBR unit test cases can be found under the program folder*

[5] *Appendix C: T-HBR instrumentations profiling report*

CHAPTER 6 – DISCUSSIONS AND CONCLUSIONS

This research has examined the strengths and weaknesses of the three different hardware sensors for collecting the health data (Arduino, stand-alone Arduino and stand-alone XBee) and two different wireless modules (XBee and RF) for communication. The aim was to create a stand-alone Arduino based hardware sensor which uses XBee radio for communication.

6.1. Discussion

The purpose of this research was to create a wireless sensor device for monitoring some of the vital signs of health and communicate with a remote computer or a service robot. The hardware device must be lightweight, cheap and reliable with unique software to process the collected data and have a communication method between hardware and software.

The research scope was to design hardware to measure the human heart rate and body temperature and develop software to analyse the collected health data as well as reducing the development time for embedded micro-controller programming. A unique and new communication method was developed to send and receive a unique data packet that specifically designed for the purpose of this project. The data packet carries two types of data: read only and changeable fields.

Every component of the hardware and software can be tested individually. This makes the process of trouble-shooting of the system easy. The communication takes place as a bridge between the hardware and software and it uses the ZigBee protocol to communicate.

6.1.1. Communication

A literature review led to the use of RF and ZigBee technology among the other existing wireless devices.

RF modules are found to be noisy, work at a lower frequency rate and are power hungry compared to XBee modules. They also have a low reliability and no security for transmitting the data. They require antenna which causes a lot of problems if the patient wants to wear the device. On the other hand, XBee alone (only XBee module for continuously transmitting the data) has no control over data (no logic access for example) and they only useful for continuously transmitting the collected data by the sensor which makes the device power inefficient. Therefore a micro-controller is chosen for work in conjunction with XBee module.

ZigBee technology has a lot of applications such as in medical devices. It makes communication easy by making a simple and secure network of XBee's which can extend the range of communication over kilometres. It has a secure 128bit data encryption and capability of saving power by putting the module into sleep mode and transmitting and receiving the data when it is needed.

ZigBee healthcare networks and applications can create a scalable network of low-power wireless nodes that are designed to sense and monitor the health and well-being of individuals. Their capabilities can make such applications possible. These capabilities include:

- Low power use
- Flexible network topologies
- Data communication security
- Wireless license-free bandwidth which is available publically
- Robust ecosystem of technology suppliers and product manufacturers

ZigBee technology is the standard of choice among the other wireless technologies due to its ability to connect a large number of devices into a single network. It enables wireless applications to use a standardized set of high-level communication protocols with cost-effective, low-power digital radios for wireless personal area networks. XBee module can be easily attached to the stand-alone Arduino. In terms of operating range and security, this project uses XBee Zednet AT, enabling point-to-point connectivity between the end device and coordinator. The system can operate at up to 100 meters in open-space.

6.1.2. Hardware

The developed hardware device benefits from the Arduino micro-controller. This micro-controller uses the ATmega chip from Atmel. Arduino is open-source hardware and comes with its own open-source software which makes micro-controller programing easy. Instead of using traditional C++ which involves a lot of overheads, initialization and etc., Arduino uses its own modified C++ language with a lot of simplifications which allow programmers to focus on the core of the software logic. Arduino is a great prototyping tool and speeds up the process of making electronics. It also has 16 digital and analogue input/output pins. As the developed sensor does not require all these pins to be used and the size of the board can be reduced by eliminating them, therefore a custom Arduino board (named as stand-alone Arduino) is made for further minimization of size, cost and weight of the micro-controller. It uses those pins of the micro-controller which are needed for processing the data received from the sensors. This allows micro-controller board to be cheaper and lighter and utilizes the hardware rather than having the un-necessary IO pins.

The sensor device uses Li-ion battery technology. These types of batteries are widely used in heavy duty and sensitive devices. Li-ion batteries are the most sensitive ones which require careful maintenance (charging for example). They can last for a long time with a very low memory effect (approximately 0). As they are rechargeable, an accurate charging mechanism is required. A charger-booster from Sparkfun Electronics is used to:

- Boost the voltage input to +5V DC from a single 3.7V Li-ion battery
- Enable the device to being charge though either a Micro-USB port or normal DC adapter

This board has an on-board protection circuit which makes charging more secure. The Li-ion batteries are flat, light, heavy duty and cheap.

6.1.3. Software

The data collected from the sensors are stored and analysed. This requires back-end software, allowing the received data to be stored in a database. A two way communication is developed to enable the software system (named as T-HBR) to communicate with the hardware.

C# programming language comes with a large framework of pre-developed components, which makes it particularly useful for Windows programming. It is full of features that make development faster and easier, usually at the cost of flexibility and/or runtime performance. It supports MySQL databases and enables a standard user-interface for Windows applications to be made.

MySQL database is fast and free for personal and commercial use and has a lot of free database management applications. It supports multiple-user availability with a high level of security and is able to manage large amounts of information.

T-HBR software has the following functionalities:

- Scans and identifies the hardware devices attached to the serial ports of a PC
- Communicates, queries, opens and closes the device within a safe mode
- Identifies all the hardware devices within the network and communicates with the correct devices which are registered within the system

- Programs the remote devices wirelessly. This gives the non-professional users the advantage of being able to change the parameters of the sensor device based on their needs. This is a unique feature which most of the existing devices in the market are not able to do
- Uses a highly adaptable, widely used and freely available 'MySQL' database. MySQL is very easy to install and maintain compared to the other database packages such as Microsoft MySQL Server. Also Microsoft MySQL Server is not free to use although has almost same functionalities as MySQL
- Uses ten different encryption algorithms. A combination of these encryption algorithm with the use of unique password, gives the high level of security on data
- Able to send e-mails and text messages to registered GPs, nurses and etc. Currently, the T-HBR software uses free G-Mail service and text messages and it can be replaced by any other mail and/or text message system (for example the hospital mail server)
- T-HBR is an object oriented and components based software. This allows re-using each part of the software individually. Each component can be tested separately and can be replaced by the developers if they are needed
- The system is able to retrieve the login information in a secure way by sending the desired information through an e-mail, text message, phone calls or etc.
- T-HBR is able to graph the temperature and heart rate between any periods of time. It can also divide each graph into two in order to compare the results side-by-side
- The system is able to generate a secure prescription (as a PDF) and send a copy to the patient, pharmacy, other GPs and etc. All this information is kept in the patient records

The T-HBR software is developed from scratch and specifically designed for this project. There is no such software in the market and it has solved a lot of problems identified in other software (for example it can identify the new hardware attached to the serial port without closing the software where in other software such as X-CTU, user requires to close the program and run it again). The T-HBR uses MVC# design model in 3 layers: Model, View and Controller. Model contains the application logic, view controls the user interface and controller takes care of the database or persistency layer. The software components can be tested individually and can be replaced without affecting the system functionalities and with no down-time.

6.2. Contribution of author

To explain the research process towards achieving the final output of the project, each stage is discussed under the following key points:

- Literature review and research the task
- Identify the needs and establish the requirements
- Plan
- Implement
- Test the results

Detailed contributions from the author for each chapter are summarised as follows:

Chapter 1: The research topic and scope of the research are studied to ensure that the goals are clearly understood.

Chapter 2: This part of the research discussed the key aspects listed of which are summarised in the literature review:

- The role of information technology in healthcare
- Vital human health signs (body temperature, heart rate, blood pressure and respiratory rate)
- The role of service robots in healthcare (demand, challenges and benefits) as well as including the role of mobile service robots to be intelligent decision making tools
- Recent technologies with wireless sensor networks and their advantages within the healthcare systems
- Wireless communication technologies (WiFi, WiMAX, ZigBee and Bluetooth) and their comparisons
- Benefits of using ZigBee in real-time healthcare devices

Chapter 3: To choose a suitable communication module and protocol, the following studies are carried out:

- Study and compare the two wireless network devices (ZigBee and RF technologies)
- Select XBee module as a low-power and secure device for the purpose of the wireless communication
- Programmed the module's firmware as the coordinator and end-device
- Setup the different XBee networks and study the XBee network security, range and reliability
- Once setup is complete, test the XBee network by writing unit test cases to transmit and receive data by both modules

Chapter 4: For developing the hardware device, the following steps are taken:

- Study existing micro-controllers and select the open-source Arduino board based on its specifications for developing the sensor (open-source hardware and software, easy programming, cheap hardware)
- Study human body temperature (skin and mean body temperature) and human heart rate (pulse oximetry)
- Create the temperature sensor using an analogue TMP36 sensor. The sensor is used as follows:
    - It is connected to the micro-controller
    - Temperature sensor is calibrated against a commercial digital thermometer
    - Micro-controller programmed to calculate the temperature read by the sensor
    - Use Burton's equation and apply it to the micro-controller software code to obtain a good estimation that is close to the human mean body temperature. The results were analysed which showed that using Burton's equation was effective and statistically significant
- For creating the heart rate sensor, a proper set of IR emitter and photo-transistor are selected
- An LM358N dual-amp is selected. The first stage is used for amplifying the signals (with Gain of 16) and the second stage as a comparator with an hysteresis
- A series of high and low-pass filters are created to eliminate the noise below 0.67Hz and above 6Hz. This enables the sensor to measure the heart rate within the ranges of 40 to 360 beats per minute
- A custom Arduino micro-controller board is created
- A Micro-SD memory card is added to the device to log the data
- Schematic diagram of the design is created
- A bread-board design of both temperature and heart rate sensors are created based on the designed schematic diagram. It is then tested with and compared to a set of existing commercial temperature and heart rate sensors
- Different batteries are tested and Li-ion is selected as the power source for the device
- To ensure maximum security is provided when using the hardware device, an existing commercial booster/regulator is selected to boost the power from 3.7V DC to 5V DC as well as charging the Li-ion battery (battery overcharging or overheating)
- The final design is carefully tested and the schematic diagram of the design is updated with the final changes
- A 2-layer PCB design of the prototype is created
- Both PCB layers are assembled with similar components values which are used on the bread-board design.

- Each unit of the final design is tested separately using both electronic devices for testing such components as op-amp and battery and software programs for testing the Micro-SD card and communication
- The developed device was tested on a group of 50 volunteers
- A suitable box was selected for the sensor device (the box was an almost complex modified version of a Omron commercial blood pressure and heart rate device)
- The cost of developing each unit sensor hardware is meticulously calculated
- Two conference papers published:
    - Wireless Network for Health Monitoring
    - ATmega and XBee-Based Wireless Sensing

Chapter 5: A complete software system is designed and the following steps simplify the various stages of the design:

- Study the importance of electronic health records (EHR)
- Select a proper programming language for the task (C#)
- Investigate the importance of data history in healthcare and study Oracle MySQL and Microsoft SQL Server
- Software requirements are selected and identified
- A conceptual view of the system as well as the software architecture are drawn up
- The micro-controller software is designed with the following functions:
    - Measuring the heart rate
    - Reading the temperature
    - Structured EEPROM access to store and retrieve the permanent data (sensor settings etc.)
- A light-weight string library is developed to overcome the problem of micro-controller limited memory
- A unique communication data packet is designed using the developed light-weight string library
- Free G-Mail's e-mail and text message forwarding integrated into the system. It enables the T-HBR software to communicate to the outside world
- A PDF writer library is written to enable the software to generate the output as a PDF file
- A zip library is designed to enable the software to compress the required documents before transmitting them by e-mail
- A comprehensive windows and terminal based programming environment are designed to enable the software to be able to program the remote device wirelessly either by modifying a field or transmitting all fields as a single data packet
- A unique micro-controller EEPROM access library is written that enables the hardware setting to be stored permanently on the micro-controller

- The end-user software is designed with the following functionalities:
  - Register a new user/patient
  - Retrieve the user login information
  - Visiting system (records the visiting information)
  - Implement chart reports (to visualize the outputs)
  - Administration tools (to control the software and database)
  - Access the patient's history and ability to update the information
  - Send e-mails and text messages to patients, GPs and health providers
  - Export results as text and PDF files as well as charts
  - Able to securely program the remote device wirelessly
- Software system is tested with a set of C# unit test cases
- Maintainability index, cyclomatic complexity, depth of inheritance, class coupling of the T-HBR software is measured
- The one conference paper that is submitted is:
  - Wireless Health Data Acquisition

6.3. Results analysis

The results of the XBee network analysis shows a high degree of reliability for transferring the data. The transmitted and received data packets are monitored and the number of failures and successes in both cases are recorded. Table 20 shows the results of the success rate in both transmitting and receiving the data packet to and from the sensor device:

# of Try	# Success	% Success
1	47	94%
2	2	4 %
4	1	2 %

# of Try	# Success	% Success
1	50	100%

Table 20: Packet success rate: received by device (left) - send to device (right)

The results indicate that the device successfully delivered 94% of the data at first, 4% the second and 2% after the fourth attempt to the software on the host PC. In addition, the software on the host PC was able to communicate with the remote device successfully (100% success rate). The maximum distance of the device and the host PC was measured to be about 30 meters (in open space with no wall and minor environment noise).

The temperature sensor gives a very good approximation of measuring the mean body temperature based on the skin temperature. It is calibrated and readings from the temperature sensor are modified using the Burton's equation. The maximum error by the temperature sensor is about 1.33 °C:

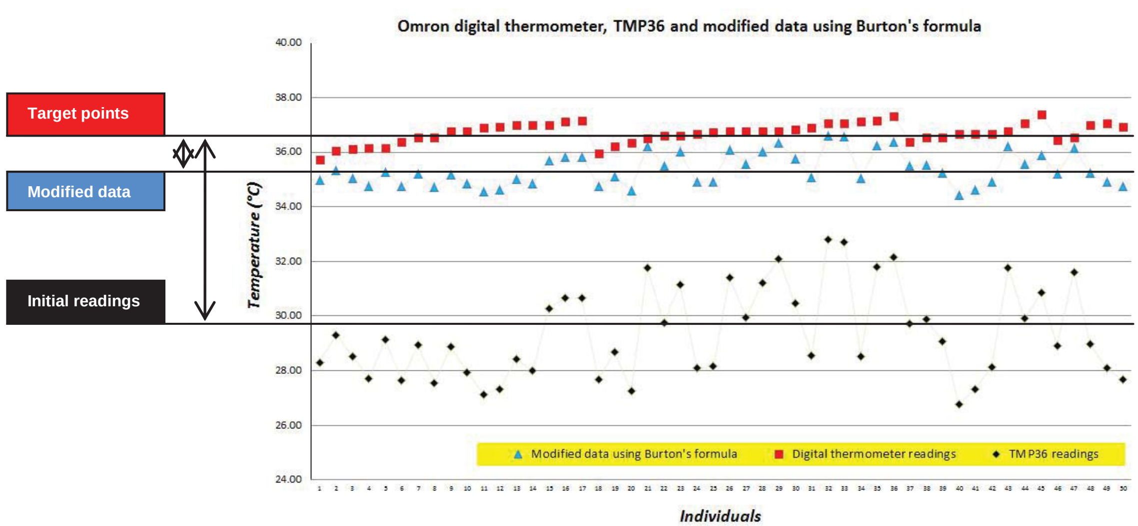

Fig 116: initial and modified vs actual temperature readings

Fig. 116 shows that the initial readings by the sensor had an approximate 7.31°C difference with the target points (based on the readings from the digital thermometer as being accurate). After modifying the readings, the difference drops to a maximum at 1.33°C[1]. The statistical analysis of the readings, proved the significance of using the Burton's equation[2].

The heart rate sensor indicates an acceptable accuracy. The developed sensor and a commercial heart rate sensor were used to read the heart rate of the 50 volunteers. Fig. 117 shows the comparisons of the heart rate readings using the sensor device and the commercial heart rate sensor on the market:

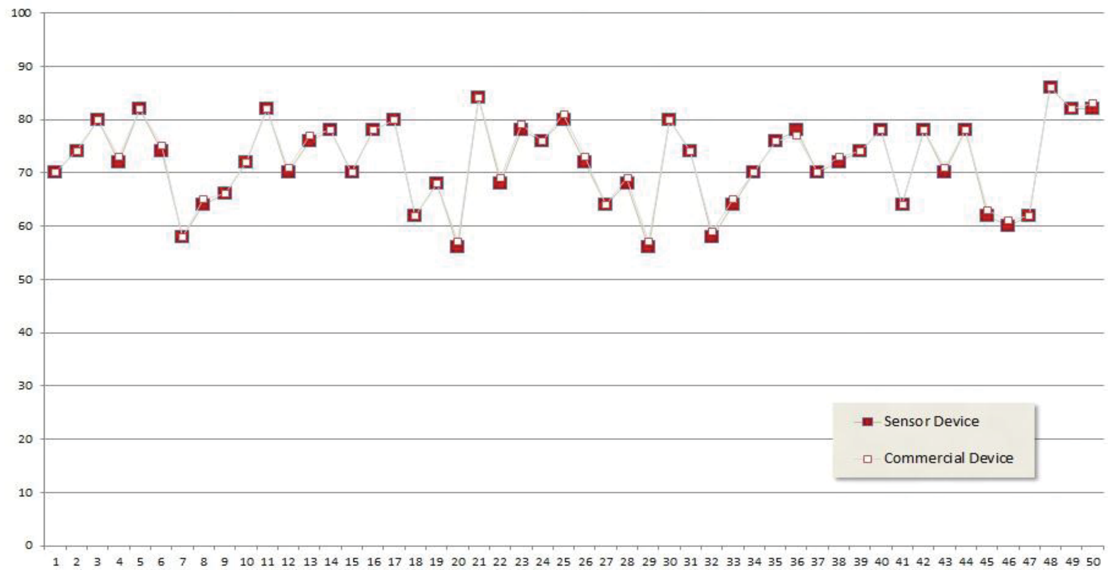

Fig 117: Comparison of the heart rate readings

The maximum difference between the readings was ±1. Although the existing devices on the market give different estimation of heart rate (possibly due to their calibration, the type of IR LED's they used and perhaps other external factors), the developed sensor appeared to have a very good estimation of heart rate[3].

	Commercial device	Sensor readings
Minimum	56	57
Maximum	86	86
Median	72	73

Table 21: Difference readings between sensor device and commercial device

[1] *Appendix D: Sensors data*

[2] *Complete details can be found in section 4.3.4.4. Temperature reading results and data analysis*

[3] *Appendix D: Sensors data*

The developed software system (T-HBR) is designed to be user friendly and easily maintained. Each component can be removed or disabled without affecting the entire system. Each function of the T-HBR software is tested separately and within the system. The major tests that were carried out by the software were:

- Stress test: load the software with a large amount of data (transmitting packet continuously from the sensor to the host PC)
- Injection attack: vulnerability of database is tested by sending a set of pre-defined SQL statements to retrieve the sensitive data and/or breaking the database
- Response time: the software system is programmed to send the command to the remote device and to receive the acknowledgement from the remote device

The T-HBR software was also tested on eight different computers with different configurations (different graphic cards, processor, RAM and hard disk etc.) The results of the test showed that the software is able to work on almost any PC although, depending on the speed of the computer. Also as the software is written in C# language, it only works on Microsoft based platforms. The data logger on the device (Micro-SD card) is able to store a massive amount of data. If the device is required to measure the body temperature and heart rate in every one hour and log the data on the memory card, the maximum file size will be approximately 5KB per day. Therefore, by using a 4GB memory card, the device will be able to log the data for more than 2000 years without being replaced. It is important to note that the data must be backed-up otherwise many years of data may be lost which would be devastating for such a sensitive device.

The hardware device packaging is a modified version of an existing commercial device (Omron heart rate and blood pressure). The box is almost 80% modified (removed all the unnecessary bits and pieces) and the final hardware PCB board, power source, sensor connector and etc. were then designed to be fit into the box. The box is fully labelled to assist the user to understand the functions of each button and sockets[1].

The TMP36 temperature sensor is a cheap analogue sensor. It is a slow sensor that requires adequate time for accurate reading. To get a good reading from the sensor, it is recommended to be attached to the body for about a minute (at least) for the sensor to settle. Fortunately, external factors such as air temperature did not cause any major error in the readings[2].

[1] Appendix G: Step by step modification of the sensor box

[2] Appendix G: Temperature sensor in use

The heart rate sensor is shown to be very sensitive, especially when affected by external factors[1]. Initially at the early stage of developing the heart rate sensor, the primary aim was to use it on the finger, similar to the existing commercial devices. However, the results obtained showed that even a tiny movement by the finger can cause a big error in the pulse readings. Therefore, the final heart rate sensor was redesigned to use the ear lobe instead of the finger due to the following reasons[2]:

- The ear lobe skin thickness is almost the same in the majority of people, which is favourably easier for pulse reading compared to the finger which has different thickness in different people
- Ear lobe is shown to be less affected by any movements compared to the finger

The best position for both IR transmitter and receiver is to position them facing each other with respect to the horizontal reference line. According to the IR emitter and detector datasheet, the typical viewing angle of the IR LEDs is about 40 degrees. If it is assumed that the receiver is fixed, then any rotation of IR emitter greater than approximately ±20 degrees[3] (up or down) with respect to the horizontal line will give serious false readings or possibly no readings from the sensor. Also the maximum distance between these types of sensors must be approximately 1±0.5cm.

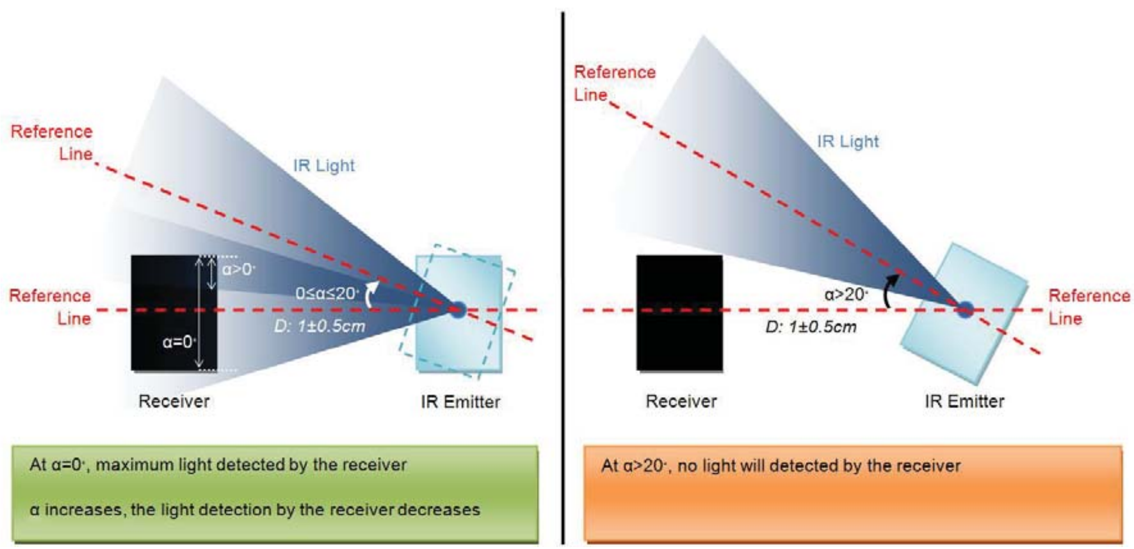

Fig 118: Effect of IR emitter rotation on light absorption by the receiver

[1] *Section 4.11. sensor error factors*

[2] *Appendix G: Heart rate IR sensor design*

[3] *Measuring the exact angle is very difficult and it is required laboratory tools*

6.4. Conclusions

The research project was successful in developing the wireless sensor network hardware and software which can be used in health monitoring applications. The hardware device is ready to be used in health organizations to monitor the patient temperature and heart rate. The use of TMP36 analogue sensor to measure the skin body temperature, gives a good estimation of a human's mean body temperature by using the Burton's equation with a maximum error of less than 1.33 °C.

The heart rate sensor uses the combination of an infra-red LED and a phototransistor. It gives a good estimation of heart rate with maximum error between -1 and +1 beat per minute. Experimental results obtained from the device showed that the sensor worked fine as long as the object is not moving rapidly. These types of heart rate devices are very sensitive to any special material on the measuring site, body motion, ambient lights and blockage in blood flow on arms or fingers. The sensor device still has room for improvement to deliver the capabilities of traditional electro-cardiograms.

The development of the buffered communication methodology for micro-controller increases the reliability of communication and security as well as saving power. It also reduces the transition synchronizations of packets by transmitting a whole packet at once which requires only one synchronization.

The XBee module presents a very effective way of transferring data between the hardware device and the host PC. Using sophisticated software, the hardware device is no longer required to be connected to a PC and programmed manually. Instead, the software is able to program the remote device wirelessly. It also hides the complexity of understanding the micro-controller programming by letting the user change some parameters and upload the code to the remote device. The users will no longer need to use the Arduino micro-controller programming environment.

Further improvements in the system can be made to reduce the size of the sensor by using a smaller micro-controller chip (for example 28MLF version) and SMD version of LM358 dual op-amp. A new sensor box can be made in a smaller size. The current sensor device is proof of the concept and there is still a lot of work can be done to improve the system.

A better micro-controller with extended memory will be beneficial. Extended memory enables the user to work with a bigger data packet and transmit a bigger chunk of data to and from the micro-controller.

Depending on the database setup, the T-HBR software can be operated in two stand-alone and server modes. If the database is setup on the host PC, the program automatically switches to stand-alone mode while if the database is setup on the server, the software will switch to the server mode. Having the database setup on the server will:

- Increase the security of data
- Decrease the cost of using the software on each computer
- Decrease the cost of software maintenance
- Increase the maintainability of the system by backing up the server rather than backing up the each individual system
- Reduce the fault tolerance

The developed sensor device and its hardware have many applications such as uses by a mobile service robot in healthcare. The host PC can be carried by a service robot and the software communicates with the sensor device. The service robot can collect other information such as gesture and voice. A combination of this information can lead to more detailed study of a patient's situation.

Considering the future health for human beings, population growth and shortage of GPs, nurses and medical facilities, further studies can be made to explore automated decision making on the collected data from a patient. However, it requires a massive study of patient's behaviour to make a correct decision by the mobile service robot.

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APPENDIX A – PUBLICATIONS

Wireless Network for Health Monitoring[1]

Wireless Network for Health Monitoring: Heart Rate and Temperature Sensor

Amir Hoshang Kioumars
School of Engineering and Advanced Technology
Massey University
Palmerston North, New Zealand
kioumarss@yahoo.com

Dr. Liqiong Tang
School of Engineering and Advanced Technology
Massey University
Palmerston North, New Zealand
L.Tang@massey.ac.nz

Abstract—**In the field of human health, collecting real-time data is vital. A system that can remotely monitor heart rate and body temperature is presented in this paper. The data was collected from a group of volunteers using the sensors developed by the research team to test the system. The Arduino micro-controller is programmed to transmit the data securely to a remote PC station using an XBee wireless network for display and storage. Power consumption by the system was minimized by activating the sensors when a command from a remote PC is received.**

***Index Terms*—Arduino micro-controller, Heart rate sensor, Temperature sensor, Mean body temperature, ZigBee wireless communication**

I. Introduction

By providing new ways for providers and their patients to readily access and use health information, information technology (IT) has the potential to improve the quality, safety, and efficiency of health care. In general, IT allows health care providers to collect, store, retrieve, and transfer information electronically. In home health, the use of technology that allows patients to monitor their own vital signs from their home and communicate results to a hospital professional wirelessly could increase the ability to address a problem before a patient requires acute care.

Improvements in wireless sensor network technologies and the size of their associated hardware have several potential applications in the medical health system. The ability to remotely monitor vital signs in real-time is a growing area of interest [1]. Portability, ease of deployment/scalability, real-time/always-on capability, reconfiguration and self-organization are some of the advantages of using a wireless sensor network in an healthcare system.

Wireless devices using some of the existing communication technologies have some limitations. Some of them are expensive and not power efficient. Others like Bluetooth limit the number of nodes that can communicate with each other at any given time [2]. Wireless sensors do not need high bandwidth connection like Wi-Fi. Instead, they need low latency and very low energy consumption for long battery lives. ZigBee technology is a good alternative to other wireless technologies. It works with low power and it is able to connect a large number of devices into a single network. ZigBee technology uses 2.4GHz frequency bandwidth. It enables wireless applications to use a standard communication protocols based on the IEEE 802.15.4 for wireless personal area networks [3]. It also offers low-latency communication between devices without requiring synchronizing the network delays.

Compact systems with a minimum training time that are low-cost, simple and affordable are highly desirable for the applications in human health care. This paper presents a wireless system and describes in details heart rate and body temperature sensors. The system is developed using a combination of an Arduino micro-controller and ZigBee technology. An experiment on a group of 50 volunteers was conducted to measure their heart rate and skin body temperature. Burton's equation [4] was applied to obtain the mean body temperature based on their core and skin body temperature and it was concluded that the equation gave a good estimation of mean body temperature.

II. System description

A conceptual view of the system is shown in Fig. 1. The core of the system consists of Arduino micro-controller hardware and software, a temperature sensor, a heart rate sensor, an XBee radio and wireless communication protocol. The sensor is wrapped around the wrist. It displays the heart rate and the mean body temperature on a character LCD, encrypts the data and transmits them to a remote PC using an XBee network. The coordinator is connected to a PC running a program to monitor and process the incoming data.

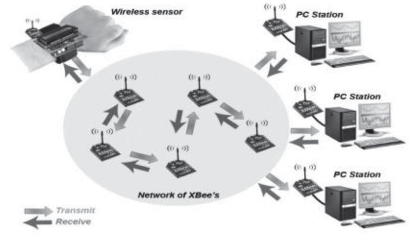

Figure 1: Conceptual view of the system

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[1] *Wireless Network for Health Monitoring, Fifth International Conference on Sensing Technology, 28th November – 1st December 2011, Palmerston North, New Zealand. pp. 378-385, ISBN 978-1-4577-0166-5*

A. Arduino micro-controller hardware

The Arduino is a single-board micro-controller thus enables electronics process in multidisciplinary projects to be more accessible [5]. The hardware consists of a simple Arduino board with an 8-bit Atmel AVR processor and onboard input/output support. The Arduino connectors allow the CPU board to be connected to a wide variety of interchangeable add-on modules known as Shields. XBee Shield enables an XBee module to be connected to the Arduino board.

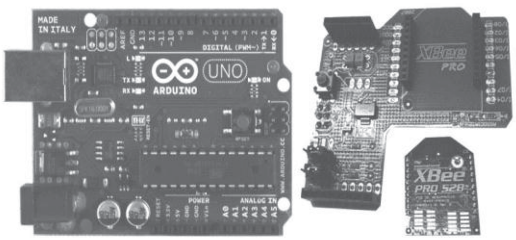

Figure 2: Arduino, XBee shield and XBee module

B. Arduino micro-controller software

The Arduino IDE is a cross-platform application written in Java. It is derived from the IDE for the Processing programming language and the Wiring project [5]. The Arduino software consists of a standard programming language compiler and the boot-loader which runs on the board. The Arduino hardware can be programmed using a specific programming language which is similar to C++. It makes programming micro-controller much easier. It can transmit the data by writing them onto the serial port using a simple serial communication command with need for synchronization, initialization and/or using interrupts. The Arduino software is free and open-source. It enormously reduces the cost of micro-controller programming.

C. XBee radio

The XBee-PRO ZNet 2.5 (formerly known as Series 2/PRO and designed to operate within the ZigBee protocol) support the unique needs of low-cost, low-power wireless sensor networks. The modules require minimal power, provide reliable delivery of data, operate within the 2.4GHz frequency band and are compatible with analogue/digital inputs/outputs adapters.

The XBee module interfaces with a host device through a logic-level asynchronous serial port [6]. ZigBee technology defines three different device types: coordinator, router and end device. The XBee shield allows an Arduino board to communicate wirelessly using ZigBee. The module can communicate up to 100 feet indoors or 300 feet outdoors (with line-of-sight) [5].

D. TMP36 temperature sensor

An analogue temperature sensor uses a solid-state technique to determine the temperature. These devices do not use mercury or temperature sensitive resistors. Instead, as the temperature increases, the voltage across the diode increases at a known rate. This is the voltage drop between the base and emitter of a transistor. The device is able to generate an analogue signal that is directly proportional to the temperature.

Compared with LM34/TMP34 (Fahrenheit output) and LM35/TMP35 (Celsius output), the TMP36 temperature sensor has a wider range from -40°C to +150°C. It does not require a negative voltage to read sub-zero temperatures. According to the TMP36 datasheet, the sensor operates within a low-voltage range from 2.7V to 5.5V and is calibrated directly into degrees °C. It has a 10mV/°C scale factor with ±2°C accuracy and has low self-heating properties. Unlike the photocell sensors, the TMP36 does not act like a resistor. This means there is only one way to read the temperature value from the sensor by connecting it directly into an analogue input of the micro-controller analogue/digital converter (ADC).

The temperature sensor has to be calibrated before use. Applying the following equations to a TMP36 temperature sensor connected to 5V power supply would give a 10-bit analogue reading into range between 0 to 5000milli-volts and convert the reading into a °C:

$$SensorOutput_{mVolts} = ADC_{readings} * (5000/1024)$$

$$T(^{\circ}C) = (SensorOutput_{mVolts} - 500)/10$$

The temperatures of different types of objects are examined by a digital thermometer (Fluke 51 K/J) and TMP36 temperature sensor to make sure the calibration gives an acceptable estimation.

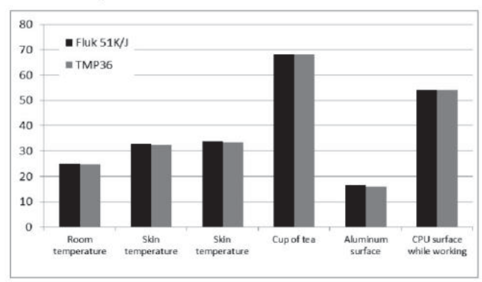

Figure 3: Temperature readings comparisons after calibration

"Mean-body temperature is defined as the mass-weighted average of tissue temperatures throughout the body" [4]. Body heat distribution can be modeled as two thermal compartments, namely the core (trunk and head) and peripheral tissues (the extremities) [4]. "Core temperature is easy to measure and temperatures are relatively homogeneous throughout the trunk and head. It is thus easy to determine an average temperature of the core thermal compartment. [4]

"Peripheral tissue temperatures are varying and widely depending on the region, environmental characteristics, and pass through while deoxygenated hemoglobin absorbs more red lights and allows more infrared light to pass through [14]. Red light is in the 600-750nm wavelength and the infrared light is in the 850-1000nm wavelength light band.

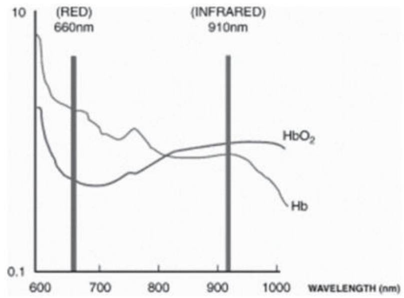

Figure 6: Infrared and red light wave length

The heart rate sensor uses an infrared light emitter that shine through a translucent site with good blood flow [15]. It has an emitter which emits the IR light. Opposite the emitter is a photo-detector or a phototransistor that receives the light that passes through or bounces back from the measuring site. There are two methods of sending light through the measuring site: transmission and reflectance.

In the transmission method, the emitter and detector are opposite each other with the measuring site in between and the light can then pass through the site. In the reflectance method, the emitter and detector are next to each other on the measuring site. The light bounces back from the emitter to the detector across the site.

There is a surge of arterial blood with each heartbeat. It momentarily increases arterial blood volume across the measuring site. This results in more light being absorbed during the surge. The waveform light signals received at the detector will show peaks with each heartbeat and troughs between heartbeats. These signals vary across different people. Some have very weak signals and need to be amplified. Also the scanned signals are noisy and need to be filtered. Therefore, a combination of high-pass filter and operational amplifier (op-amp) is needed to minimize the noise and amplifying the signals.

F. *Heart rate sensor setup*

Fig. 7 is a simplified diagram of hardware setup. The signals out from a phototransistor are passed through a high-pass filter, an amplification stage, and then a low-pass filter. The signal is finally sampled by the micro-controller.

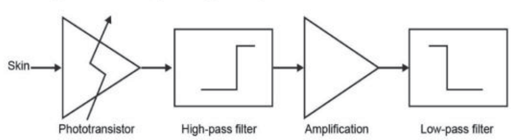

Figure 7: Simplified diagram of hardware

The light is emitted by the IR emitter, passes through the measuring site and is detected by the phototransistor. These devices operate at 940nm. An ADC on a micro-controller allows variable readings to be collected from the detector. The detector is a NPN transistor that is biased by incoming IR light.

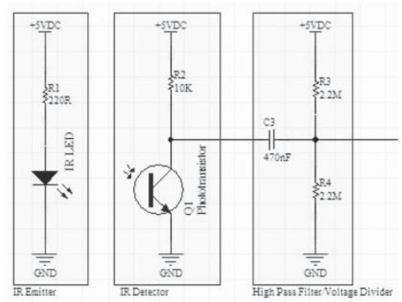

Figure 8: IR sensor/phototransistor and high-pass filter

The output voltage of the phototransistor is approximately half of the supply voltage. This means the phototransistor and resistor R_2 act as a voltage divider. Therefore it considered that the resistor value of the phototransistor (R_p) is equivalent to the value of the resistor R_2:

$$R_{2,p,3,4} = R_{2,p} + R_{3,4} = 1{,}105{,}000\Omega$$

$$f_{HighPassFilter} = \frac{1}{2\pi R_{2,p,3,4} C_3} \approx 0.3Hz$$

The filtered signals go to input pin 3 of LM358 and are amplified. The LM358 has two internally compensated op-amps. The first stage is used as an amplifier and the second is used as a comparator:

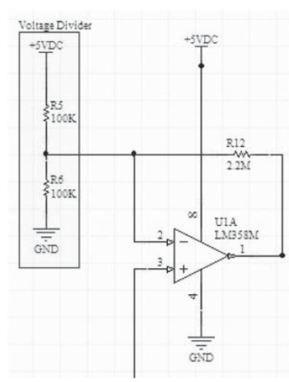

Figure 9: Signal amplification

$$Gain = \frac{R_{12}}{R_{5,6}} + 1 = 45$$

The output of the op-amp passes through a low-pass filter with a cut-off frequency of 6.03Hz to remove the high frequency signals above the threshold:

$$f_{LowPassFilter} = \frac{1}{2\pi R_7 C_4} \approx 6Hz$$

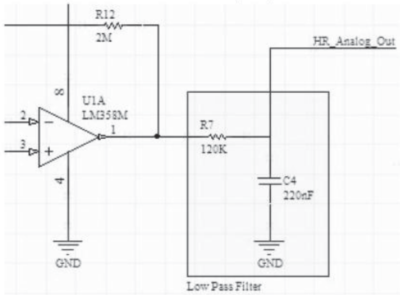

Figure 10: Low-pass filter

The filtered signals carry the information desired: the human heartbeat or pulse. The output of pin 1 of LM358 is analogue and carries a set of numbers, which indicates the amplified voltage level detected by the photo-detector. Although it is possible to measure the heart rate based on these readings, it would be easier to have a digital output. Therefore, the second part of the LM358 is used as a comparator. Hysteresis for most comparator circuits is the difference between the input signal voltages that makes comparator's output is fully ON or fully OFF. Hysteresis can be added to a circuit to reduce the sensitivity to noise or a slowly moving input signal. A comparator's hysteresis range can be increased by adding a resistor between the output and the PLUS input terminal. This creates a feedback loop. When the output makes a transition, the feedback changes the voltage at the PLUS input which increases the voltage difference between the PLUS and MINUS inputs. Fig. 11 shows the hysteresis on the LM358 comparator:

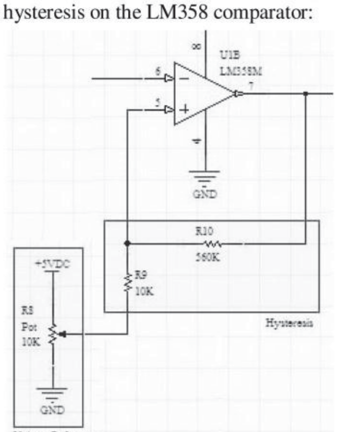

Figure 11: Threshold voltage reference and hysteresis

The output of the comparator (pin 7) is used to drive a LED indicating a heartbeat. It creates a digital signal (high or low) and it will be used to calculate the heart rate. Fig. 12 shows the complete schematic diagram of the hardware.

Liquid crystal displays (LCD) come in different shapes, colors and sizes. The Arduino uses the Liquid Crystal library to communicate with the LCD display. An ElectroLite 16*2 character LCD is connected to the micro-controller to display the heart rate and temperature readings.

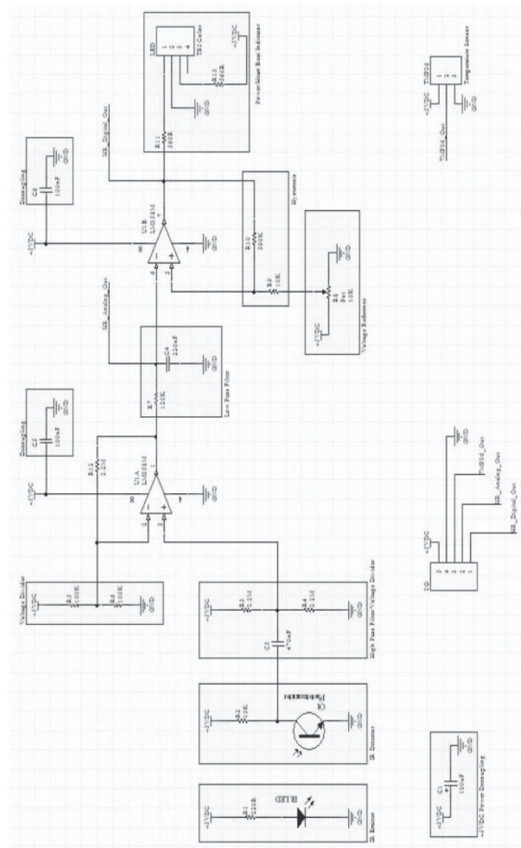
Figure 12: Schematic diagram of hardware

G. Experiment and testing

A prototype of heart rate sensor was developed. A number of experiments and tests including both hardware and software were carried out during the development stage. A trial was made on the prototype on a number of individuals (a group of 50 volunteer). Fig. 13, 14, 15 and 16 show a sample analogue and digital output from the prototype:

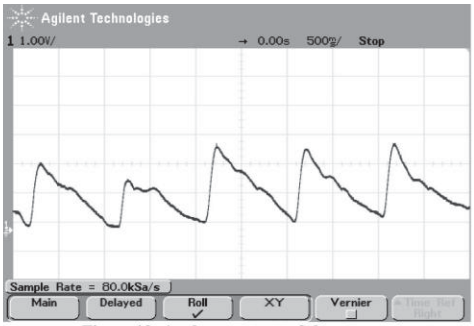

Figure 13: Analogue output of the op-amp

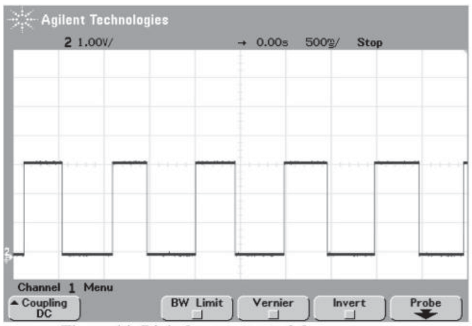

Figure 14: Digital output test of the comparator

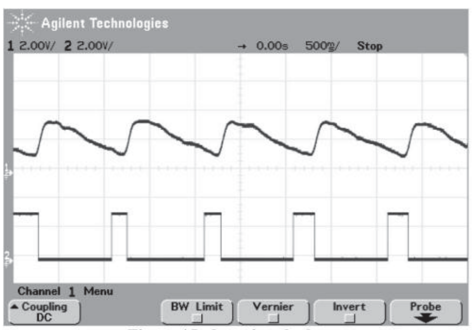

Figure 15: detecting the beats

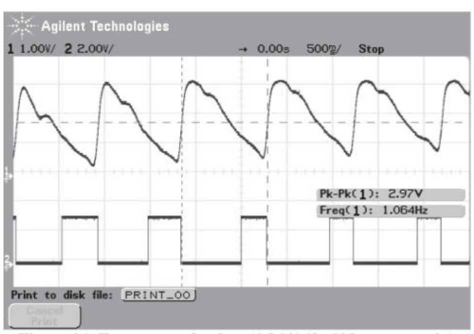

Figure 16: Frequency of pulses (1.064*60~64 beats per min)

In order to save power, the sample rate for IR is 10 seconds and the XBee module will go into sleep mode until a proper command is received from the coordinator. Two analogue and digital samples are read. The analogue signals are then transmitted to the remote PC for further analysis and the digital samples are used to calculate the heartbeat by multiplying the number of detected pulse by 6 to get the beats per minute.

H. Wireless communication

The heart rate and temperature signal obtained using the sensor developed by this research is able to be sent to a computer through wireless communication. Therefore, the system is able to monitor the status of the heart rate and body temperature.

ZNet 2.5 firmware enables routers or end devices to communicate with the coordinator by default which makes point to point communication simple [6]. Serial data is sent to the XBee router (or end device) connected to the Arduino micro-controller and received by coordinator.

The Arduino's EPROM has 512 bytes in length. It can be programmed using Arduino's EPROM library. The program on the micro-controller works as follow:

a. The Arduino EPROM is programmed with a unique number assigned to each patient. This number acts as a primary key in order to store the data into a database

b. The temperature and heart rate is calculated

c. The above values are attached together as a single packet using comma space

d. The packet is encoded

e. The printed data (packet) on the Arduino's serial port is transmitted to the remote PC

I. Pulse error factors

Although the prototype has many advantages, including cost effectiveness, lightness and ease of use for everyone, there are several factors which may cause errors in measurement which need to be taken into account when using the sensor:

i. If users have some special material on their measuring site such as nail polish or covered by reflectance material, it may absorb the light emitted from the LED and change the light transmitted though the body.

ii. Body motion may cause a lot of noises which will reduce the reliability of the device and error in readings.

iii. If the blood flow is blocked due to pressure on arms or fingers, correct measurement becomes impossible.

iv. The device can cancel out the effects of ambient lights. However, if the light becomes too strong, the device might only cancel out some of effects and this may cause errors.

v. If the sensors are not properly attached on the measuring site, it may detect a variety of noise, resulting in inaccurate measurement.

III. FUTURE WORK

This paper presents an Arduino/XBee based wireless health monitoring system and the sensors. An Arduino micro-controller is used to process the data acquired by the sensors and transmit to a remote computer using XBee network. Although the Arduino micro-controller is small, there is space to further reduce the size make the sensor even smaller and lighter.

Further improvement now focuses on developing software to analyze the data transmitted from the sensors. The software aims to enable two way communications and remotely change monitoring requirement based on the individual situation. The system will allow the micro-controller to be programmed remotely, increase the security of data using a more advanced encryption algorithm.

In terms of the micro-controller and the associated PCB boards, further study focus on making the boards smaller and cheaper to further reduce the cost, weight and size of the sensors

Currently the sensors use a 6 to 26 volts input. Future improvement will look at the power supply with smaller size and lower voltage input. A long-life, light and cheap battery with maximum current input and low input voltage will be an ideal option especially if it can be charged with different power sources.

IV. CONCLUSION

This research was to develop a wireless health monitoring system that is capable of measuring two vital signs of health and communicating with the end device. An initial exploratory study on the system presented has been conducted on a group of 50 volunteers from 18 to 37 years old. The results of the study identified an acceptable measurement of the human mean body temperature and heart rate.

The research work presented has established a base for such a healthcare monitoring environment. The developed sensors are capable of reading the mean body temperature and the heart rate. Through the wireless network, a remote computer is able to obtain the real time data, perform the analysis and plot the result.

With this prototype system, more features can be added such as the functionalities to detect blood pressure and glucose level. With the further development on the reliability of sensor nodes, security and data analysis etc. the system together with the remote monitoring software will have an enormous application area not just in human health care field.

V. ACKNOWLEDGMENT

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AMIR HOSHANG KIOUMARS

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ATmega and XBee-Based Wireless Sensing[1]

ATmega and XBee-Based Wireless Sensing

Amir Hoshang Kioumars
School of Engineering and Advanced Technology
Massey University
Palmerston North, New Zealand
kioumarss@yahoo.com

Dr. Liqiong Tang
School of Engineering and Advanced Technology
Massey University
Palmerston North, New Zealand
L.Tang@massey.ac.nz

Abstract—**Health monitoring is a challenging research area. This research aims to develop a cost effective and reliable wireless sensor for collecting real-time health vital signs such as heart rate and body temperature. The literature review has led to the use of various micro-controllers for such applications. This paper presents a wireless sensor developed based on the ATmega micro-controller and XBee protocol. The sensor is capable of storing the data to an expandable memory card and/or transferring them to a remote computer. The developed sensor is low-cost, lightweight and compact. The final system has made a significant move towards these goals.**

Index Terms—ATmega micro-controller, Wireless heart rate and temperature sensor, XBee, Micro-SD memory card

I. Introduction

Wireless sensor network has been widely used for collecting signals from standalone or remote sensors. It also has a great potential in medical and health applications. In recent years, research using sensor network to monitor real-time signals is growing [1]. With the fast development of network communication, wireless sensor network for healthcare has become a great solution as it provides "portability, ease of deployment/scalability, real-time/always-on and reconfiguration and self-organization".

ZigBee provides an upper-level specification for the 802.15.4 standard, which is required by some applications that need secure networking and a low data rate [2]. It has a long battery life with average current drawn of 30~40mA for transmitting the data. This current drawn is low enough to last almost 100hrs on a single AA battery [2]. It also has a secure data transfer with 128-bit encryption and inexpensive hardware. Target applications for ZigBee include wireless sensors such as medical monitoring.

The limitations on the existing wireless communication technologies such as cost and power consumption can be improved using ZigBee wireless sensor network [3]. ZigBee has an efficient low-power connectivity and ability to connect a large number of devices into a single network [4].

Wireless devices that require minimum training time and are cost effective, light, small, simple and affordable are highly desirable especially in medical applications. This paper presents a wireless sensor for collecting and monitoring the health signs. The developed sensor uses ATmega micro-controller chip. The communication is done using an XBee radio. The system is able to reliably collect the heart rate and body temperature. It has the capability of transmitting the data in real-time and stores them on an expandable memory card simultaneously. The memory card can increase the reliability of data collection in case of loss of communication. It also enables a complete history of the data to be stored and read separately without the device being presented.

II. System Description

The conceptual view of the system is illustrated in Fig. 1. Patient heart rate and body temperature are collected by the sensor. The data can be transmitted to a remote computer through a network of XBee's. They can also be stored on a memory card simultaneously. Depending on the distance from the PC, the data can be routed through several XBee routers to reach the remote coordinator.

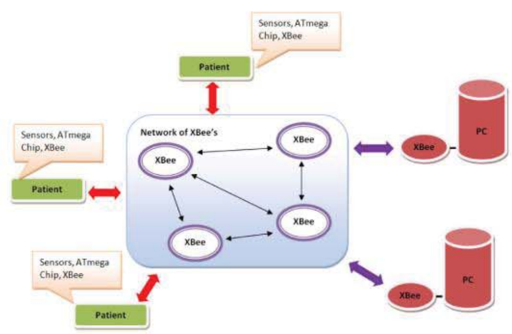

Figure 1: Conceptual view of the system

The system consists of an ATmega micro-controller with an extendable Micro-SD memory card; a wireless heart rate and body temperature sensor to collect the data and a XBee module to transmit the data to a remote PC. The sensor device is aimed to be small and light and can be wrapped around the wrist.

A. Heart rate and temperatur sensor

In creating the heart rate sensor, both an infrared emitter (940nm wave-length) and a detector (phototransistor) are used. The phototransistor is biased by incoming IR light [5]. The light is emitted by the IR emitter, passes through the

[1] *ATmega and XBee-Based Wireless Sensing, Fifth International Conference on Automation, Robotics and Applications, 6th to 8th December 2011, Wellington, New Zealand. pp. 361-365, ISBN of 978-1-4577-0328-7*

measuring site and is detected by the phototransistor. With each heartbeat, the heart contracts and there is a surge of arterial blood which momentarily increases blood volume across the measuring site.

Fig. 2 is a simplified diagram of the hardware setup:

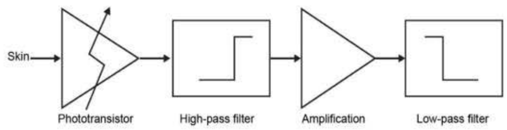

Figure 2: Simplified diagram of the hardware

The signals acquired by phototransistor are passed through a high-pass filter which filters all the frequencies below 0.3Hz. The filtered signals are then amplified with a LM358 dual-amp amplifier with the Gain of 45. The amplified signal passes through a low-pass filter with a cut-off frequency of 6Hz. The LM358 first stage output is then connected to an analogue input of the micro-controller.

The second part of the LM358 is used as a comparator. The output of the comparator is used to drive a LED, indicating heartbeats. It creates a digital signal (1: high – 0: low) that can be used to calculate the heart rate. Fig. 3 shows the complete schematic diagram of the sensor setup:

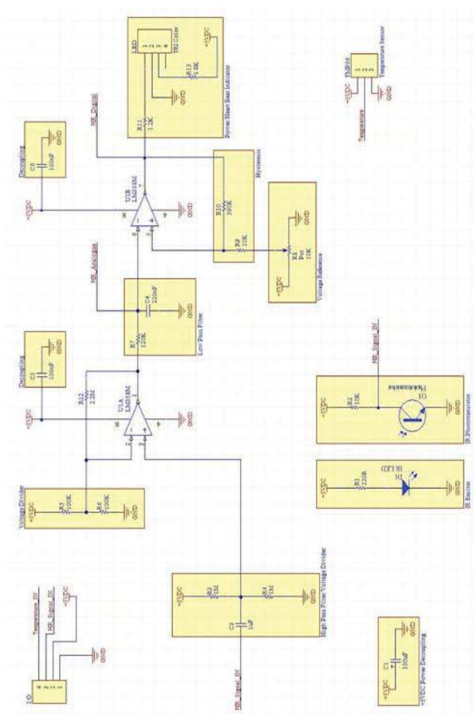

Figure 3: Sensor setup

Detailed hardware setup of the heart rate and temperature sensor is fully described in a paper titled "Wireless Network for Health Monitoring: Heart Rate and Temperature Sensor" that is published previously by the researcher team.

The TMP36 temperature sensor is operated within a low-voltage range from 2.7V to 5.5V and is calibrated directly into °C. It has a 10mV/°C scale factor with ±2°C accuracy [6]. It is stable with large capacitive loads and has low self-heating properties. To read the temperature value from the sensor, its output can be directly connected to an analogue input of the micro-controller. The temperature reading can be calibrated by applying the following equations, assuming the voltage supply is 5VDC. The first equation will give a 10-bit analogue reading into range between 0 to 500mV and the second equation convert it into a °C:

$$SensorOutput_{mVolts} = ADC_{readings} * (5000/1024)$$

$$T(^\circ C) = (SensorOutput_{mVolts} - 500)/10$$

B. ATmega micro-controller

The ATmega328 chip can be used by itself in a breadboard or a prototyping board in order to make the prototype smaller, cheaper and lighter. A pre-built Arduino Mini board also has a small size. The cost of having a pre-built Arduino board can be minimized by designing a circuit board based on the ATmega chip. The circuit board can be made by adding just the bare-bones circuitry needed to support the ATmega chip. Fig. 4 shows the 28pins ATmega168/328 pins layout:

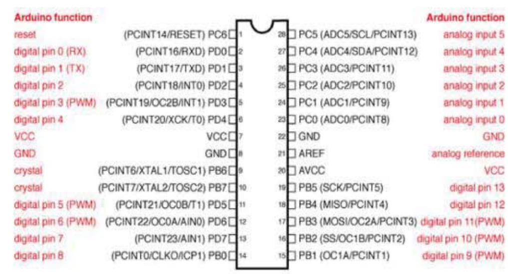

Figure 4: ATmega328 pins layout [7]

A 10k-ohm pull-up resistor is connected to 5V supply from the RESET pin on the chip. It will prevent the chip from resetting itself during normal operation. The RESET pin reboots the chip when pulled down to the GND. It is connected to a push button to enable user to reset the micro-controller.

The ATmega328 runs on 16MHz clock speed. Therefore it needs a 16MHz external clock to be connected to the chip and grounded with two capacitors running to ground from each of those pins. Fig. 5 shows the ATmega328 micro-controller setup:

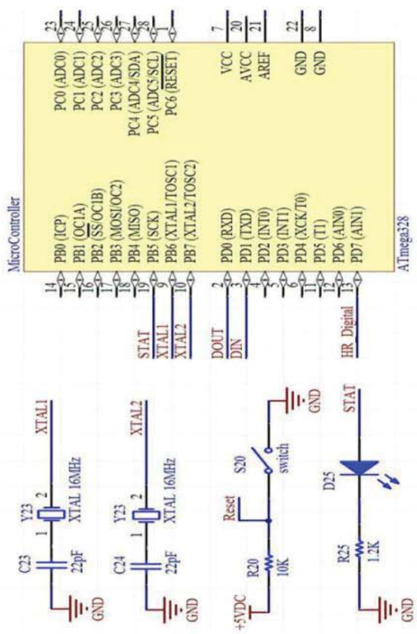

Figure 5: ATmega328 setup

C. Power source

The Lithium-Ion batteries are addressed by the Li-Ion technology. These types of batteries can be found in most sensitive electronic devices [8]. According to their datasheet, they have a 3.6~3.7V output rating; used in voltage sensitive and high current devices and can be on standby for months.

Li-Ion batteries are operated safely within the designated operating voltages. However, they become unstable if they are charged to a higher than specified voltage or discharged too low [8]. The internal battery equipment cuts off when the battery discharges to about 3.0V per cell and stops the current being flow. If the discharge continues to about 2.7V per cell or lower, the battery's protection circuit puts the battery into a sleep mode.

D. Power-cell charger – booster

The Power-cell board from Sparkfun Electronics [9] is a single cell Lithium Polymer (LiPo) boost converter (to 3.3V and 5V). It has a micro-USB and a DC power charger on-board. A single cell LiPo battery can be connected to the board with a selectable 3.3V or 5V output. The micro-USB charger uses the MCP73831 (Miniature Single-Cell, Fully Integrated Li-Ion, Li-Polymer Charge Management Controllers) and allows the battery to be charged up to 3.7V at a rate of 500mA [10]. The MCP73831/2 devices are highly advanced linear charge management controllers for use in space-limited, cost-sensitive applications. According to its datasheet, the MCP73831/2 employs a constant-current/constant-voltage charge algorithm with selectable pre-conditioning and charge termination [10].

Figure 6: Power cell charger - booster

The boost converter is based on the TPS61200 from Texas Instruments. It has a solder jumper to select 5V or 3.3V output and an under voltage protection of 2.6V. It also features a quiescent current less than 55uA and an over temperature protection [9]. This board does not have reverse polarity protection so adding a diode to protect the board from being damaged is a solution.

The TPS6120x devices provide a power supply solution for products powered by a single-cell, two-cell, or three-cell alkaline, NiCd or NiMH, or one-cell Li-Ion or Li-polymer battery [9]. The device provides output current up to 600mA at a 5V output while using a single-cell Li-Ion or Li-Polymer battery. The boost converter is based on a fixed frequency, pulse-width-modulation (PWM) controller using synchronous rectification to obtain maximum efficiency [9]. Because the developed sensor needs 5V supply to operate, a 3.7V Li-Ion battery is used to boost the output voltage to 5V at 600mA maximum.

E. Micro-SD memory card

Secure Digital (SD) is a non-volatile memory card format developed by the SD Card Association (SDA) [11] for use in portable devices. Micro-SD cards are typically formatted as FAT16 and FAT32. The ubiquity of FAT16 and FAT32 allows those cards to be accessed on virtually any host device with an SD/Micro-SD card reader.

Depending upon the ability of a specific SD card, it may support various combinations of the Bus types and transfer modes [11]. Serial Peripheral Interface Bus (SPI) is primarily used by embedded micro-controllers. This bus type supports only 3.3V power and communications. One-bit SD separates command and data channels and a proprietary transfer format. Micro-SD card families are run at 3.3V. After power-up, the host must communicate with the Micro-SD card up to a maximum clock rate called the Default Speed (DS), which is a bus clock up to 25MHz [11].

An extended memory card enables the device to be able to store the data captured by the sensor. This feature allows the device to save the data in both on-line and off-line communication mode. It is an important capability to record the data in case of communication failures such as XBee module stops working or the receiver is down. It also adds the capability to have a complete history of logged data which can be read separately without the actual device being presented.

Micro-SD cards are small in size, lightweight, cheap and they operates with 3.3V supply. The developed device can support up to 4GB Micro-SD card with FAT16 or FAT32 format with the use of SPI and One-Bit SD bus transfer mode.

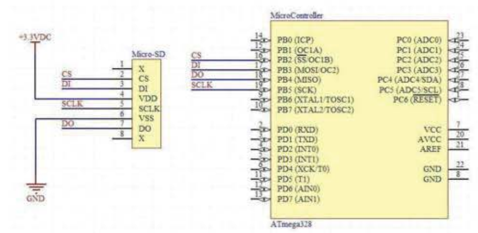

Figure 7: Micro-SD card and ATmega328 connections

F. XBee module

Each XBee radio (for example Series 2) has the capability to directly gather sensor data and transmit them without the use of an external micro-controller [12]. This means, the XBee offers some simple output functions so that basic actuations can also take place without an external micro-controller being present.

Using XBee alone has some limitations. The single biggest limitation is that the standalone XBee radio does not allow access to any kind of logic. Also it has limited input and output pins, with no simple way to extend them. This means no decisions can be made on the local device and no standalone operations can be performed besides transmitting data [12].

Using XBee series-2 (with the ZNet 2.5 firmware) allows coordinator, routers or end devices to communicate with the coordinator by default. This makes point to point communication easy. Serial data is sent to the XBee router (or end device) connected to the ATmega micro-controller and received by coordinator. Fig.8 shows the XBee connection to the ATmega328 micro-controller chip:

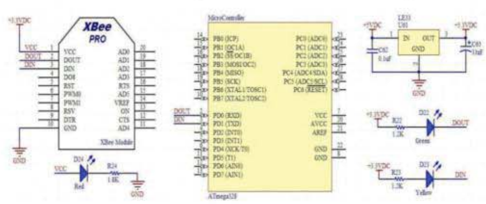

Figure 8: XBee pins and ATmega chip

G. Final design and testing

The final design is a modular design and consists of a two layers PCB.

The top layer is used to place the XBee module, 3.3V voltage regulator and LED's (indicating power, heartbeats, send and transmit). In addition, a copper plate is placed as a reset button. The digital signals change by 1 to 2 V while Analogue signals can be changed by some micro-V. A ground plane is placed under XBee module to minimize any interference cause by the RF signals.

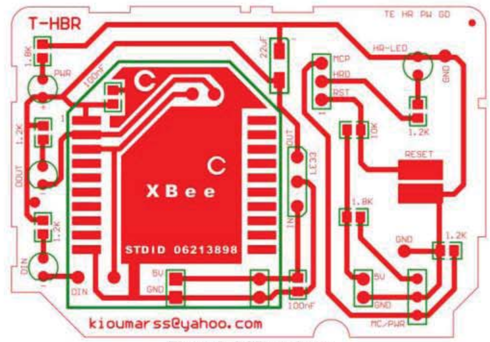

Figure 9: PCB top layer

The micro-controller, Micro-SD card connector and heart rate sensor are placed on bottom layer. All the necessary components for each major part are placed close together in order to make the debugging easy. Two 100nF decoupling capacitors are placed close to ATmega micro-controller chip and one for LM358 op-amp.

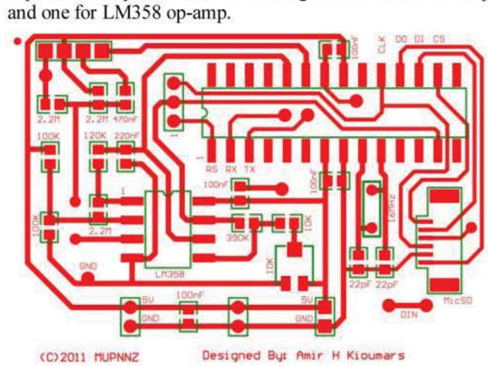

Figure 10: PCB bottom layer

H. Sensor setup- testing

A prototype of heart rate sensor was developed. A number of experiments and tests including both hardware and software were carried out during the development stage. A trial was made on the prototype on a number of individuals (a group of 50 volunteer). Fig. 11 shows the final developed sensor:

Figure 11: Sensor design

Fig. 12, 13, 14 and 15 are presenting the sample analogue and digital output from the prototype device:

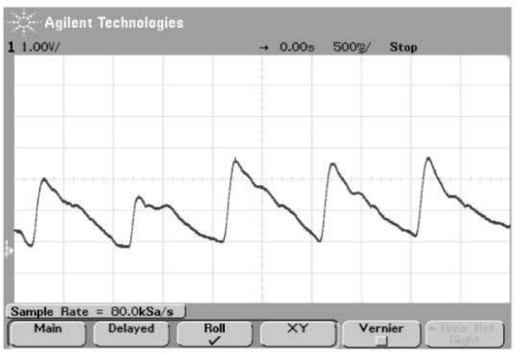

Figure 12: Analogue output of the LM358

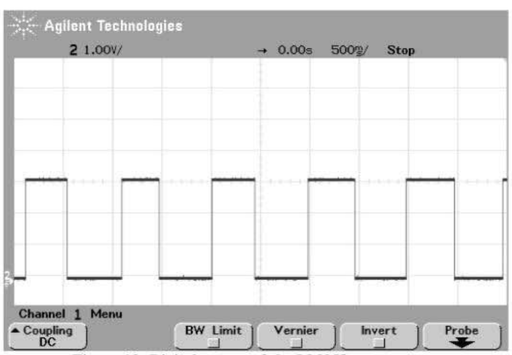

Figure 13: Digital output of the LM358 comparator

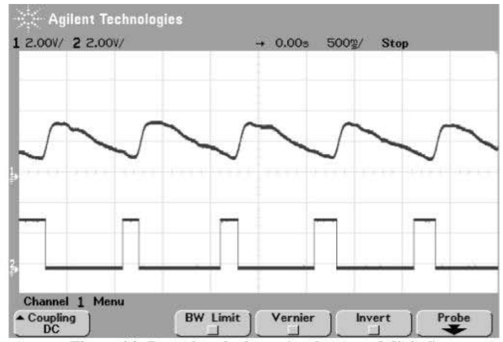

Figure 14: Detecting the beats (analogue and digital)

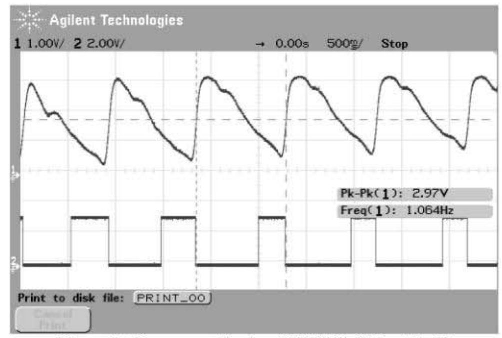

Figure 15: Frequency of pulses (1.064*60~64 beats/min)

The body temperature samples are collected using a digital thermometer and TMP36 sensor. Fig. 16 shows the differences between the actual readings from digital thermometer and TMP36 temperature sensor.

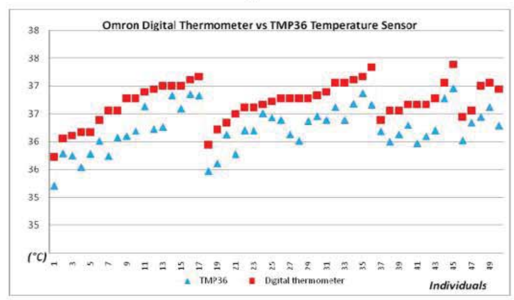

Figure 16: TMP36 and digital thermometer temperature comparisons

The differences in readings when comparing the TMP36 temperature sensor with the digital thermometer (less than one degree °C after applying the Burton's equation [13]) are due to external effects such as sealing the sensor which is placed in the ear. Also the TMP36 sensor is not as accurate as digital thermometer which is specifically designed for measuring the body temperature.

III. FUTURE WORK

Further improvement now focuses on developing software to analyze the data transmitted from the sensors. The software aims to enable two way communications and remotely change monitoring requirement based on the individual situation. It allows the micro-controller to be programmed remotely, increases the security of data using a more advanced encryption algorithm and creates a unique packet protocol for communication. The software also aims to use a central database to store the data and be capable of reading the data stored on the memory card separately.

IV. CONCLUSION

In conclusion, the aim of the research is to develop a cheap, light and small wireless health monitoring system that is capable of measuring healthcare signs and communicating with the end device. The research work presented builds a base for such a healthcare monitoring system and the sensors developed are capable of transferring data and logging the complete history on an expandable memory card.

An initial exploratory study has been performed on a group of 50 volunteers from 18 to 37 years old. The results of the study identified an acceptable measurement of the body temperature with maximum error of less than one degree °C (after applying the Burton's equation) and heart rate with maximum error of ±2.

V. ACKNOWLEDGMENT

The authors would like to thank Mr. Ken Mercer and Mr. Antony Wade from School of Engineering and Advance Technology Massey University New Zealand for technical support and help received from them.

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AMIR HOSHANG KIOUMARS

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Wireless Health Data Acquisition[1]

Wireless Health Data Acquisition: A Component-Based Monitoring System

Amir Hoshang Kioumars
School of Engineering and Advanced Technology
Massey University
Palmerston North, New Zealand
kioumarss@yahoo.com

Dr. Liqiong Tang
School of Engineering and Advanced Technology
Massey University
Palmerston North, New Zealand
L.Tang@massey.ac.nz

Abstract— **In the field of human health, collecting and analyzing real-time data is crucial. Information technology (IT) has the potential to improve the quality, safety and efficiency of healthcare by enabling the service providers and their patients to access to health information. IT allows healthcare providers to collect, store, retrieve and transfer information electronically. Patients will be able to monitor their own vital signs from their home and communicate results to their service providers wirelessly. This will increase the ability to address a problem before a patient requires acute care and maintain the quality of their life by enabling them to be close to their families and relatives. This paper presents a novel component-based monitoring system (T-HBR). T-HBR supports a multi-user environment, has a high level of security and is able to communicate with a remote computer or service robot wirelessly. The experimental results of the software demonstrate the high degree of reliability of the system.**

Keywords-component; Electronic Health Records, Wireless Programming, Lightweight Strings, T-HBR Software, MySQL Database, Emails and Messages, XBee Wireless Communication

I. INTRODUCTION

"An electronic health record (EHR), electronic patient record (EPR) or computerized patient record (CPR) is an evolving concept defined as collecting of electronic health information about individual patients systematically" (Gunter, T.D. and Terry, N.P, 2005). EHR might be in comprehensive or summary form, including medical history, medication and allergies, immunization status, laboratory test results, radiology images, vital signs, personal stats like age and weight and billing information [1]. In EHR, the medical record should accurately reflect the course of disease and indicate the probable cause as well as provide additional functionality, such as interactive alerts to clinicians, interactive flow sheets, and tailored order sets, none of which can be done be done with paper-based systems [2].

Electronic devices are used to obtain patient health data such as taking the patient's x-rays, CT and MRI. Most hospitals subscribe to online medical resources, which provide quick access to updated medical information. EHR can reduce the cost, improve the quality of care, promote evidence-based medicine, keep the patient records and mobilize the communication [3]. Information is used to automate day-to-day processes, thus helping to reduce administration costs which in-turn it can free up time and money for patient care. EHR systems provide access to clinical data for research that can accelerate the level of knowledge of effective medical practices and have the advantages of being able to connect to many electronic medical record systems with almost no errors.

Cost effective, lightweight, simple and affordable wireless hardware devices and their software that require minimum training time are highly desirable especially by healthcare providers [3]. This paper presents a novel components based software system called T-HBR. T-HBR supports multi-user availability and a high level of security as well as being able to communicate with the remote device, collect the data, store them in a database and transmit commands to the remote device. The development of the buffered communication methodology for micro-controller increases the reliability of communication and security as well as saving power. It also reduces the transition synchronizations of the packets. The proposed software is easy to understand, maintain and requires minimum training time.

II. SYSTEM DESCRIPTION

The system developed is based on the wireless sensor device and XBee communication. The conceptual view of the system is illustrated in Fig. 1.

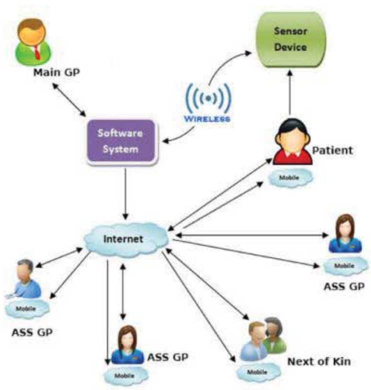

Figure 1: Conceptual view of the system

[1] *Computerized Patient Health Records, 14th International Conference on E-Health Networking, 10-13th October 2012, Beijing, China. (Submitted)*

The software is installed in the host PC and communicates with other service providers, sensing devices and patients through a network. The sensors used in the system can collect patient heart rate and body temperature and the data can be transmitted to the computer using a low-cost and power efficient XBee radio. Depending on the distance from the PC, the data can be routed through several XBees to reach the destination. The data then can be viewed and analyzed by the general practitioners (GPs). The feedback can be returned to the patient, patient's next of kin and other GPs via e-mail or text messages.

A. T-HBR software

The structure of the T-HBR software system consists of three major parts: User action/feedback (view/user interface), functional/logic (utilities/logic) and data view/persistency (MySQL database).

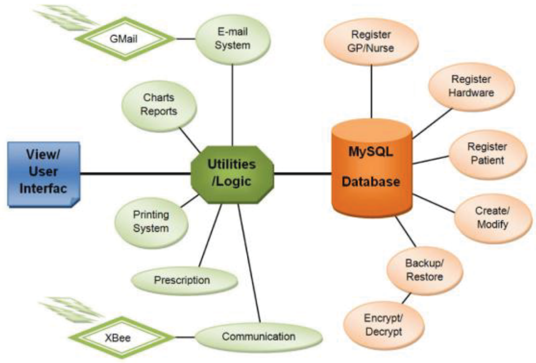

Figure 2: T-HBR software conceptual view

A 2-tier architecture consists of a presentation layer and a domain layer. Domain layer classes represent the problem domain entities (for example patient) and are usually bound to some database access facilities [4]. The software system presented in this paper uses a 3-tier architecture which is more abstract than 2-tier. The presentation layer in this architecture is divided into presentation and logic. A much more precise form of 3-tier architecture can be divided into two Model-View-Controller (MVC) and Model-View-Presenter (MVP). MVC framework frees developers from a lot of extra work required in the construction of Model-View-Presenter applications. In MVC, views and controllers are connected automatically. It supports multiple GUI platforms and allows a flexible MVP-based application to be created with almost no extra cost.

B. Arduino micro-controller

Arduino micro-controller is used for creating the hardware sensor. It uses ATmega chip on-board. It has 32KB flash memory and maximum of 4KB Static RAM (SRAM). The micro-controller processes the data based on the defined functions. The results of processing are stored in the SRAM. The actual available memory is slightly less than 4KB. In addition to the SRAM, there is a 512KB EEPROM available, which allows a small amount of data to be stored permanently. This can be done using Arduino EEPROM library. Fig. 3 shows the micro-controller data flow diagram:

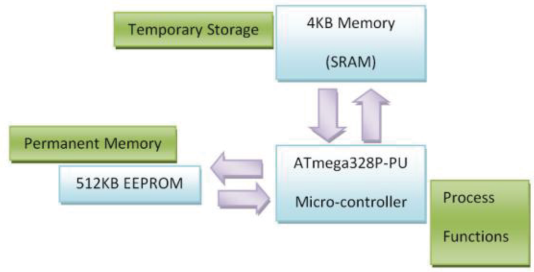

Figure 3: Micro-controller data flow diagram

EEPROM is able to hold the data even when the power is removed. It is used to store patient basic information such as first and last names, date of birth, gender, identification number (health ID for example), temperature and heart rate sensor settings, and the hardware identification number (HUIDN). The HUIDN is programed by the manufacturer in order to label the device for using within the network. It is the key to transmitting and receiving the data to and from the micro-controller.

C. Micro-controller structured EEPROM access

On an Arduino, EEPROM access can be difficult in terms of storing different types of data. Arduino EEPROM only reads/writes single bytes. It has two template functions 'read' and 'write' defined by the Arduino libraries. However, using these functions requires the data offset to be known. These templates are not easy to use [5]. On a deeper level, the AVR library has a more complex API for other kinds of integers and buffers. However, it still needs to remember the offset and size of the data. There is a keyword called 'EEMEM' which flags the data as they are stored in the EEPROM but it is still necessary to know the data size and offset. Therefore, a single structure is necessary to represent the entire contents of data to store and retrieve in and out of EEPROM. A structured EEPROM access is proposed. It uses macros to read and write fields. This technique uses a single 'struct' to represent the entire contents of the EEPROM, so macros can be used to read and write fields.

D. Lightweight strings

Since the 'print' was introduced with Arduino 0012, several classes including HardwareSerial, LiquidCrystal, Ethernet Client/Server and NewSoftSerial have been written to leverage its text-rendering engine. Getting formatted text to output devices requires either writing custom code or turning to expensive alternative solutions like sprintf() command.

A new lightweight string (LString) is introduced in this paper. LString is a new lightweight print-derivative string class that renders text into a character buffer. LStrings allows the print renderer for any devices, even those that do not directly support print-style text formatting. They do not have their own buffers. Instead, they rely on pre-allocated static buffers that are passed in at the point of construction. Unlike strings, LStrings do not allocate memory dynamically, even when the result of a print command, assignment or concatenation operation seems to exceed the current buffer's size. In these cases, the excess data is simply discarded and the string correctly terminated. Because of these constraints, LStrings will never cause a buffer overflow, a string's buffer will always be valid memory and the original buffer, and buffers will always contain valid and NULL-terminated string data.

E. Structured communication packet

The process of communication with the micro-controller requires clear time synchronization. Transmitting and receiving requires power. Therefore, sending a block of data at once will reduce the power consumption and the need for synchronization. In order to have a more reliable and faster communication, a custom data packet is introduced. The data packet consists of a set of LString data types with total length of 128 bytes. Fig. 4 shows the data packet fields and Table 1 shows the data packet descriptions:

Figure 4: Data packet

Table 1: Data packet descriptions

	Length (Byte)	Description	Changeable
D ID	10	Device id number – programed by manufacture	N
FN	30	Patient first names	Y
LN	20	Patient last name	Y
DB	10	Patient date of birth	Y
SX	1	Patient gender	Y
ID	10	Patient health ID (or any other ID number)	Y
TS	5	Temperature sample size	Y
TD	5	Delay between each temperature sample	Y
HS	5	Heart rate sample	Y
HD	5	Delay between each heart rate sample	Y
LD	1	Flag to enable/disable write to Micro-SD card	Y
SZ	8	Micro-SD card size	N
SN	8	Micro-SD card serial number	N
DT	7	Micro-SD card date of manufacture	N
WP	1	Micro-SD card write protect	N
FO	1	Micro-SD card format	N
CP	1	Micro-SD card copy protect	N

The data packet is constructed in either micro-controller or host PC side. All the fields are manipulated one at a time. The data packet is the heart of the two-way communication. It is carefully designed based on ATmega328 memory limitations (4KB SRAM).

The changeable fields (as shown in Table 1) can be updated by the host PC to store the permanent data into the micro-controller's EEPROM. The rest of the fields can be used to retrieve the information from the hardware device. The data packet then is encoded using our proposed data encryption algorithm before transmitting to the host PC.

The host PC can transmit the data packet to the desired remote device. It is require broadcasting the packet until it receives and the acknowledged by the remote device. Fig. 5 shows the packet-broadcasting schema:

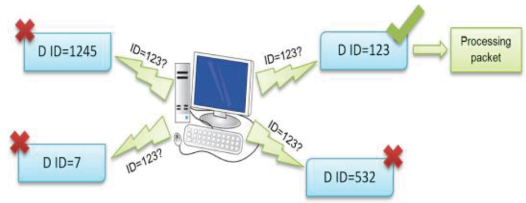

Figure 5: Packet broadcasting

Host PC broadcasts the data packet to the entire network nodes. All the hardware devices receive the packet, decode it and look at the header to extract the hardware ID. If this ID is matched with the pre-programed 'hardware ID' inside the micro-controller then the packet will be examined otherwise it will be discarded.

F. Command line programming

This option allows the user to program the remote device filed-by-field. It does not require the whole data packet to be transmitted. Instead, it only transfers the desired value, resulting in faster updating of the remote device. Fig. 6 shows the online programming window with some examples.

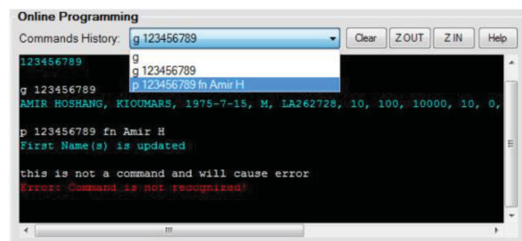

Figure 6: Online programming

The result of each successful command creates a data packet, which is created on the PC side. When it is transmitted, the micro-controller decodes the data packet. Based on the command type, the micro-controller will carry out a proper action and send the acknowledgement back to the PC.

G. Gmail and Gmail to SMS

Almost all organizations have their own e-mail server. There are some paid options exists but Gmail is one of the best choices for a robust free service by providing a free Sending Mail Transfer Protocol (SMTP). According to the Google official website, Gmail account allows user to blocks spam emails, group messages and the relevant responses, talk face-to-face with voice and video, access e-mails from the phone regardless of the device type, labels and filters the messages and automatically separates important emails from everything else and focuses on what really matters. This unique and free capability allows medical providers to send e-mails and short message service messages (SMS) to their patients and keep the record of message transactions. T-HBR uses free Gmail and Gmail to SMS services with the capability of sending the e-mails through a proxy server.

H. MySQL database

Hospitals and medical practitioners have had to contend with numerous challenges such as interoperability, privacy, and business process pressures that have slowed their investment in information systems as compared to other industries. In fact, one of the top priorities in the healthcare industry is to broaden the use of electronic records and other health information technology to help reduce costs and dangerous medical errors, and improve patient safety. Healthcare applications including practice management solutions, electronic medical records or electronic health records, monitoring equipment and digital imaging systems all rely on a clinical data repository, which requires a high-performance transactional database for processing patient information. MySQL is the cost-effective, high performing and reliable data repository used by many of the leading solution providers [6]. High performance, improved profitability, multi-platform support, ease of installation and configuration, zero administration and high reliability are some of the benefits of using the MySQL.

I. Database backup and restore

One of the key functionalities of the administrator is to maintain the database. T-HBR enables the admin user to backup and/or restore the database. It also can encrypt the database backup in order to increase the security. The most common way to back-up a MySQL database is by using 'MySqlDump' (is used to dump a database or a collection of databases for backup) and 'MySQL Administrator' (performs administrative operations such as configuring, monitoring and starting and stopping a MySQL server) files which comes with the MySQL package. MySQL Administrator is rather easy to use by developers, but when it comes to the client or end-user, they need easier way to backup the database.

The software uses its own backup and restore classes. It uses ten different encryption algorithms to backup the database as well as a password. A combination of password and encryption algorithm makes the backup more secure. In order to restore the database safely and avoid any conflict with the existing database, the software creates a clean backup from the existing database using a password and an encryption algorithm. The password is generated using a random text generator (a string with 10 characters length) and an encryption algorithm is randomly selected. It then restores the desired database. If the restore operation is successful, then the previous backup will be deleted, otherwise it will be restored (roll-back the changes).

All the above operations are hidden to users and reduce the user workloads. Instead they just need to do the backup and/or restore by a simple click. Backup and restore must have exactly the same 'password' and 'encryption algorithm'. Violating either of them will stop the restore operation.

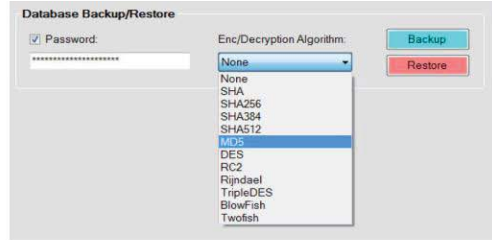

Figure 7: Database backup and restore

J. Charting

Charts are often used to ease understanding of large quantities of data and the relationships between parts of the data. The software allows GPs to see the heart rate and temperature visually and enables them to compare the data over two distinct periods of time. In addition, the software is able to save the high quality image of each graph, change all the elements of the graph such as color, fonts, line thickness etc. ZedGraph is a class library, user control, and web control for .NET, written in C#, for drawing 2D line, bar, and pie charts [7]. It features full, detailed customization capabilities, but most options have defaults for ease of use. Fig. 8 shows a sample output of the graphs for heart rate and temperature.

Figure 8: Heart rate and temperature graphs

The software system allows graphs to be compared over two distinct times. It give GPs a clear visualization of the patient heart rate and body temperature over time to see if there is/are any major changes happened and when. Fig. 9 shows an example of comparisons graphs over two different times:

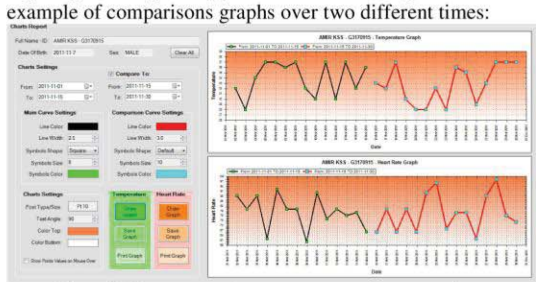

Figure 9: Heart rate and temperature graphs - comparisons

K. Visiting a patient and patient records

It is important to have a clear observation and issue the right prescription to the right patient. Therefore, by selecting a patient from 'Patient ID' list, the patient's information is displayed on the form. It allows the GP to ask some security questions based on these fields for further confirmation.

Heart rate and temperature values can be either inserted manually or acquired from the remote device wirelessly. After submitting the information to the database, they cannot be altered. Examiner information (name and ID of the person that already logged in to the system and visiting the patient); date and time of the visit are attached to the data automatically before submitting to the database. This will reduce the risk of any denial and there will be a responsible person for any visit.

GPs are allowed to send the prescription to other GPs, patient and patient's next of kin. This information will be sent to their mobile device automatically if their number is registered as a secondary forwarding address within their Gmail account. In addition, GPs may wish to attach a heart rate and temperature graph to the e-mail. Therefore, in order to reduce the size of data and have faster delivery, all this information (include a PDF file of prescription and charts) is compressed as a ZIP file and attached to the e-mail. The prescription is issued as a PDF file so no one will be able to alter its contents. Fig. 9 shows a sample visit by 'Dr. Mark Mories' with health identification number 'NZHID123'. He also wishes to send the prescription to his patient e-mail address though a proxy and print his prescription:

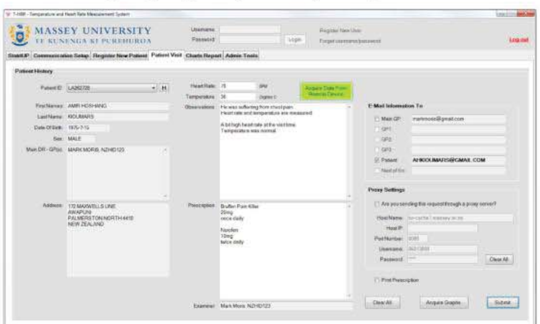

Figure 10: Visiting a patient

It is possible to have access to the patient history and visits in order to make a better decision by GPs. The patient history is displayed in a descending order (starts from latest visit dates) as color-coded to make a clear identification between date of visits, observations and prescribed medications. The patient's history also can be updated.

L. PDF writer class

Portable Document Format (PDF) is an open standard for document exchange. It is used for representing documents in a manner independent of application software, hardware, and operating systems and facilitates the capture, exchange, preservation and protection of healthcare information.

A PDF writer method is proposed in order to save the patient's prescription in this format. PDF files do not allow patients to change the contents of the prescription, resulting in increasing the security of information.

M. Validator/information analyzer

It is important to validate the information before inserting it into the database. Therefore, a unique validator class is introduced to validate the information supplied by the user. This helps the user to find any errors in data insertion and have a consistent database.

Information analyzer class has also been introduced to extract important information supplied by the user. This will reduce the number of individual fields on the forms to get data from user. For example, the user can insert the patient's address, additional phone numbers and e-mails in one field (contact details for instance) and the information analyzer will extract this information intelligently.

N. Compress file utility

A utility class is introduced to create a standard windows compression file system (ZIP). This class automatically reads the contents of the folder belonging to each patient, compress the files and creates a single ZIP file to transmit over the network. The maximum ZIP file created by this class is very small (less than 50KB) with high quality graphs pictures. This allows the data to be transferred faster and in one transaction while keeping the original quality of the graphs (they are stored as a picture).

O. Configuration settings file

Configuration setting contains all the necessary information that T-HBR needs to run. MySQL server information, Gmail mail service settings and required folders paths are encrypted using MD5 encryption algorithm and stored in this file. This allows administrators to change from one mail server to another by only update its settings within the configuration file without being required to modify the program code, for example. Access to the contents of this file requires an encryption key.

P. Threat detector

The database is the most important part of the T-HBR software. It stores patient's details and health information. These data need to be protected and secured. Therefore, a thread detector mechanism is proposed. It continually monitors the user's behavior from login to logout. If, for example, login attempt failed, it notifies the user with a warning. If the user fails to login to the system several times, the system identifies this action as an anonymous attack. It then locks all the program resources and closes the program. The software will not be run until the program vendor or system administrator unlocks it. The attack threshold number can be changed (increase or decrease) by the system administrator.

Q. Retrieve information

User must be registered and login to the system in order to use the software. The login information is encoded and stored into the database. It is always possible that a user loses or forgets his/her ‘username’ and/or ‘password’. The system allows the user to send a request to retrieve the login information. The user must include her/his general information such as name, e-mail address and phone number. There are two options which allow the user to indicate which login information needs to be retrieved: username and password. In addition, the user must accept an acknowledgment before ending the request. This acknowledgement informs the user about the risk of trying to retrieve someone else’s login information, for example. The validator validates all the fields before sending the request. Fig. 11 shows a sample request to the administrator and the email received by him/her in order to retrieve the login information. The administrator may wish to send the information by e-mail or contact the person by phone.

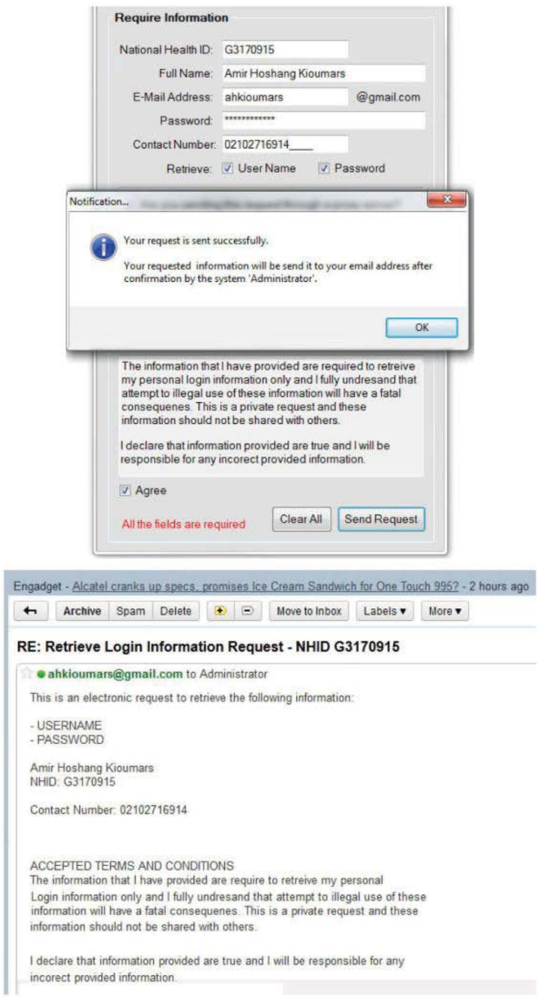

Figure 11: Sending request and receiving e-mail

R. Remote device query

T-HBR software is able to collect and retrieve the information from the remote devices. Each hardware device must be registered within the database otherwise even if the device is in use, the software system will not be able to see it. It also gives the user the ability to restart the device remotely in case of any problem. If T-HBR identifies that the hardware device is not attached to any patient yet, it will enable the user to query patient information from the database and program the remote device with the selected patient information. This is a big advantage over existing systems which are required to be attached to the computer to be programed.

Figure 12: Remote device query

S. Software quality assurance

As a part of software quality assurance and testing, a set of tests are performs on the T-HBR software system to make sure the software performs as is expected. Maintainability index, cyclomatic complexity, depth of inheritance and class coupling are measures. A set of unit tests are performed on each module of the system. Instrumentation, memory and sample profile reports are also measured.

III. FUTURE WORK

Further improvements in the system can be made to reduce the size of the sensor by using a smaller micro-controller chip (for example 28MLF version) and SMD version of LM358 dual op-amp. A new sensor box can be made in a smaller size. The current sensor device is proof of the concept and there is still a lot of work can be done to improve the system.

A better micro-controller with extended memory will be beneficial. Extended memory enables users to work with a bigger data packet and transmit a bigger chunk of data to and from the micro-controller.

Considering the future health for human beings, population growth and shortage of GPs, nurses and medical facilities, further studies can be made to make automated decision making. We are currently working on intelligence decision making algorithms by studying the patient’s behavior and gathering more information by other sensors.

Although making the software intelligent is very difficult and requires broad study of the human being behavior, we are currently working on other aspects of human behavior such as gesture and voice recognition. These signs in addition to heart rate and body temperature are aimed to be used in order to make software intelligent so it would be able to issue a prescription and send it to the patient in a matter of time.

IV. CONCLUSIONS

This paper presents the development of a software system to retrieve, store and analysis the health data acquired from the wireless sensor device wirelessly.

The development of the buffered communication methodology for micro-controller increases the reliability of communication and security as well as saving power. It also reduces the transition synchronizations of packets by transmitting a whole packet at one transaction, which eliminates the need for synchronization between two XBee modules.

The XBee module presents a very effective way of transferring data between the hardware device and the host PC. Using sophisticated software, the hardware device is no longer required to be connected to a PC and programed manually. Instead, the software is able to program the remote device wirelessly. It also hides the complexity of understanding the micro-controller programming by letting the user change some parameters and upload the code to the remote device. The users will no longer need to use the Arduino micro-controller programming environment.

Depending on the database setup, the T-HBR software can be operated in two stand-alone and server modes. If the database is setup on the host PC, the program automatically switches to stand-alone mode while if the database is setup on the server, the software will switch to the server mode. Having the database setup on the server will increase the security of data, decrease the cost of using the software on each computer, decrease the cost of software maintenance, and increase the maintainability of the system by backing up the server rather than backing up each individual system and reducing the fault tolerance.

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[6] http://www.mysql.com

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Amir Hoshang Kioumars

Received Bachelor of Software Engineering from Massey University New Zealand and currently is completing a Master of Engineering (Electronics and Computer System Engineering). His project is Intelligence Decision Making for Mobile Service Robots in Healthcare. He is working as a mathematics and computer programming tutor at Massey University. He has many years industrial experience in computer programming.

He previously worked with Massey University New Zealand on developing software for Next Generation of Network Resiliency (NGN-R) and the automated pollen identification machine (AutoStage). His research areas of interests are in electronics, mathematics, database programming, micro-controller programming and wireless sensor networks.

Dr. Liqiong Tang

Received BEng from SWPU in China and PhD from the University of Liverpool, UK. She used to work at Gintic (SIMTech), Nanyang Technnlocal University in Singapore. Then she joined Massey University in New Zealand and worked in the School of Engineering and Advanced Technology.

She has been the principle supervisor for Master and PhD projects for many years and involved in a number of industrial research projects. Her main research interests are mechatronics system design, robotics, intelligent control, sensing technology, micro-controller based automated systems and the applications in industry and healthcare.

APPENDIX B – MICRO-CONTROLLER UNIT TESTS

Two way communication unit test

```
void setup() {
  // initialize serial communication:
  Serial.begin(9600);
   // initialize the LED pins:
   pinMode(13, OUTPUT);

   Serial.println ("START WORKING");
}

void loop() {
  // read the sensor:
  Serial.println ("Waiting...");
  delay (2000);
  if (Serial.available() > 0) {
    int inByte = Serial.read();
      Serial.println ("Recieved");

    switch (inByte) {
    case 'h':
      digitalWrite(13, HIGH);
      Serial.println ("HIGH");
      break;
    case 'l':
      digitalWrite(13, LOW);
      Serial.println ("LOW");
      break;
    }
  }
  delay (2000);
}
```

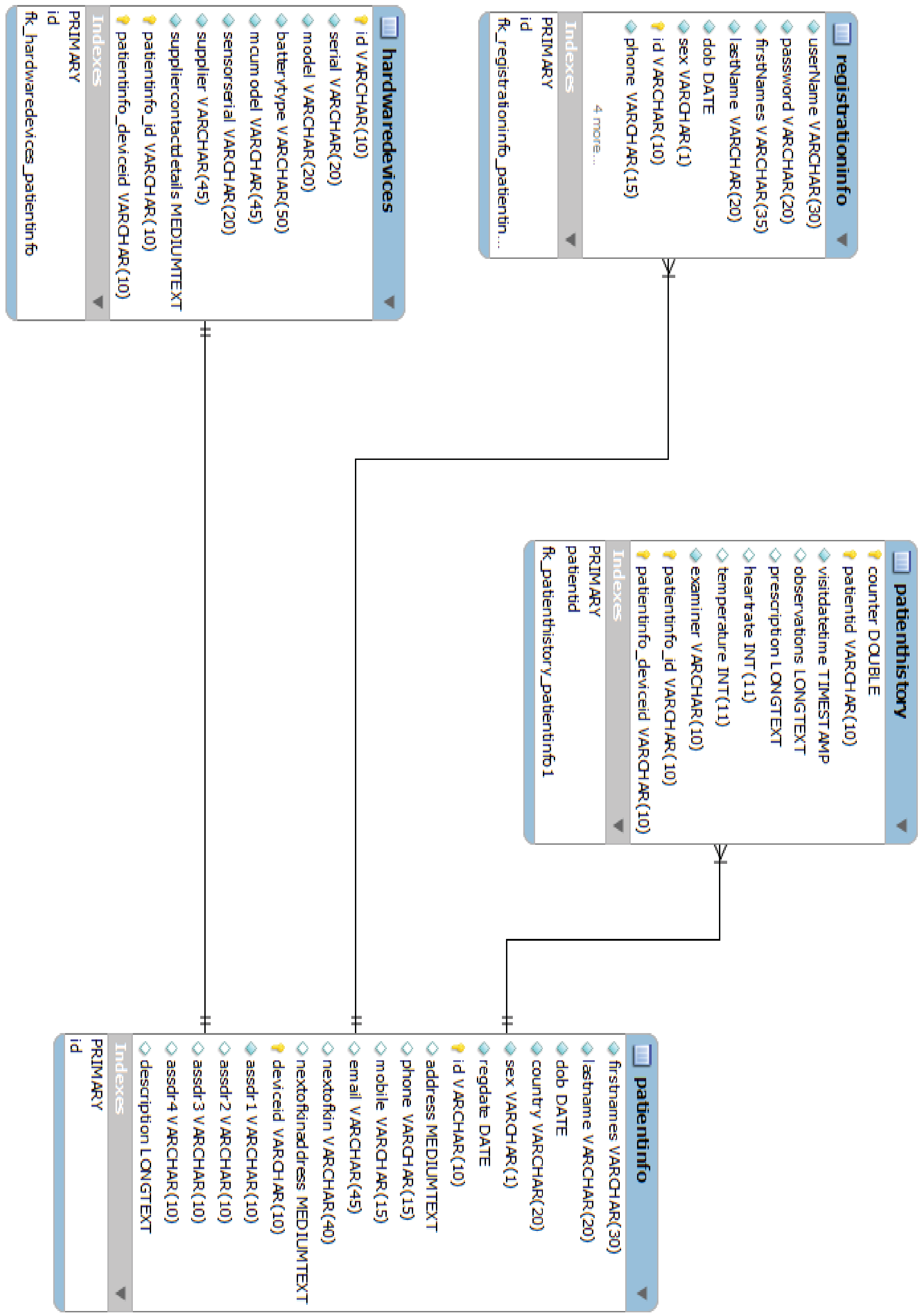
Micro-SD unit test

```
struct sd_raw_info disk_info;

byte incomingByte;
long int address;
byte tempBytes[2];


void setup()
{
  Serial.begin(9600);
  delay(1000);

  if(!sd_raw_init())
     Serial.println("MMC/SD initialization failed");

  print_disk_info();
}


void loop()
{
    int i;

    if(Serial.available()>0)
    {
         incomingByte=Serial.read();
        switch(incomingByte)
        {
            case 114:
               readDisk();
               break;
            case 119:
                writeDisk();
                break;
            default:
                break;
        }
    }
}


int writeDisk()
{
    int i, j, temp;
    byte low, high, inByte;

    Serial.println("\n\nWriting on Disk...");

    for(i=0; i<50; i+=2)
    {
          if(Serial.available()>0)
          {
                inByte=Serial.read();
                if(inByte==113)
                   return 0;
          }
          temp= random(0, 1000);
          Serial.print(temp,DEC);
          Serial.print("  ");

          //Convert int to 2 bytes
          low=temp&0xFF;
          high=temp>>8;
          tempBytes[0]=low;
          tempBytes[1]=high;

          if(!sd_raw_write(i,tempBytes,2))
            Serial.print("Write error");
```

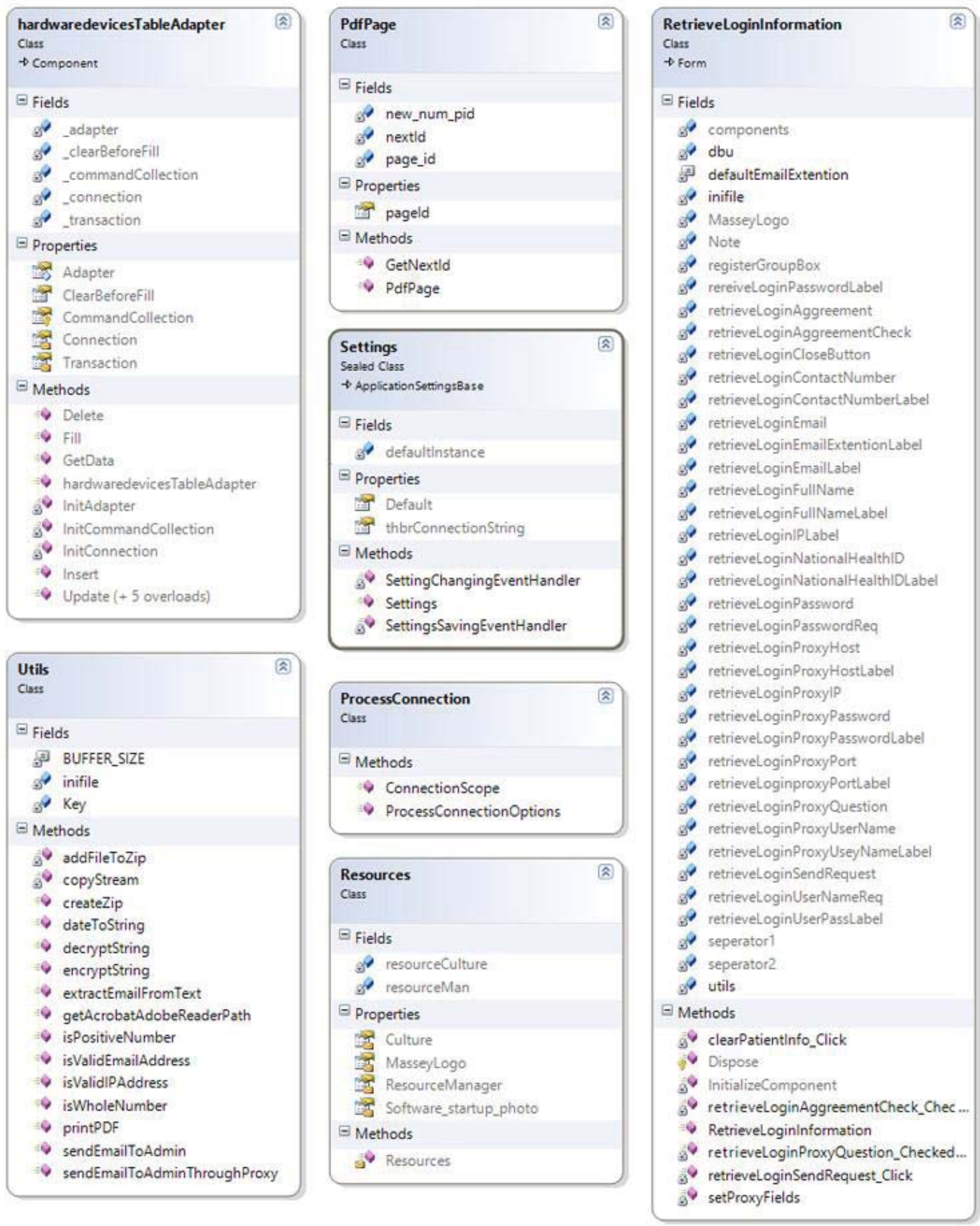
```
          sd_raw_sync();
          delay(1);
      }
    return 1;
}


int readDisk()
{
    byte low, high;
    byte info[2];
    int i, result;
    Serial.println("\n\nReading from Disk...");

    for(i=0; i<50; i+=2)
    {
          sd_raw_read(i,info,2);

          low=info[0];
          high=info[1];
          result=high<<8;
          Serial.print(result+low,DEC);
          Serial.print("  ");
    }
}


int print_disk_info()
{
    if(!sd_raw_get_info(&disk_info))
      return 0;

    Serial.print("rev:    ");
    Serial.print(disk_info.revision,HEX);

    Serial.print("serial: 0x");
    Serial.print(disk_info.serial,HEX);

    Serial.print("date:   ");
    Serial.print(disk_info.manufacturing_month,DEC);
    Serial.print("/");
    Serial.print(2000+disk_info.manufacturing_year,DEC);

    Serial.print("size:   ");
    Serial.print(disk_info.capacity,DEC);

    Serial.print("copy:   ");
    Serial.print(disk_info.flag_copy,DEC);

    Serial.print("wr/pr.: ");
    Serial.print(disk_info.flag_write_protect_temp,DEC);
    Serial.print('/');
    Serial.print(disk_info.flag_write_protect,DEC);

    Serial.print("format: ");
    Serial.print(disk_info.format,DEC);

    Serial.print("free:   ");
    Serial.println (sd_raw_available(),DEC);

    return 1;
}
```

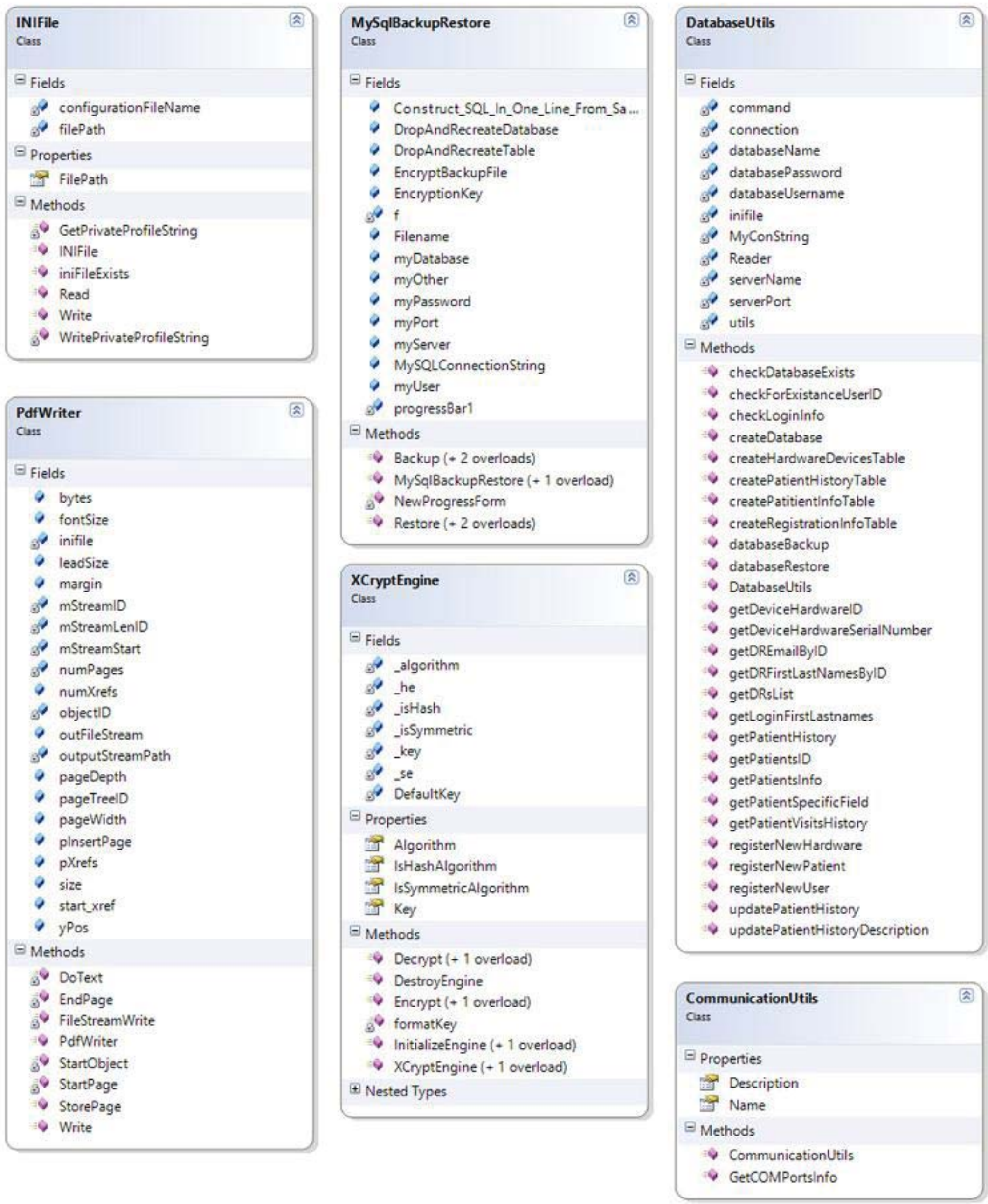
APPENDIX C – T-HBR SOFTWARE

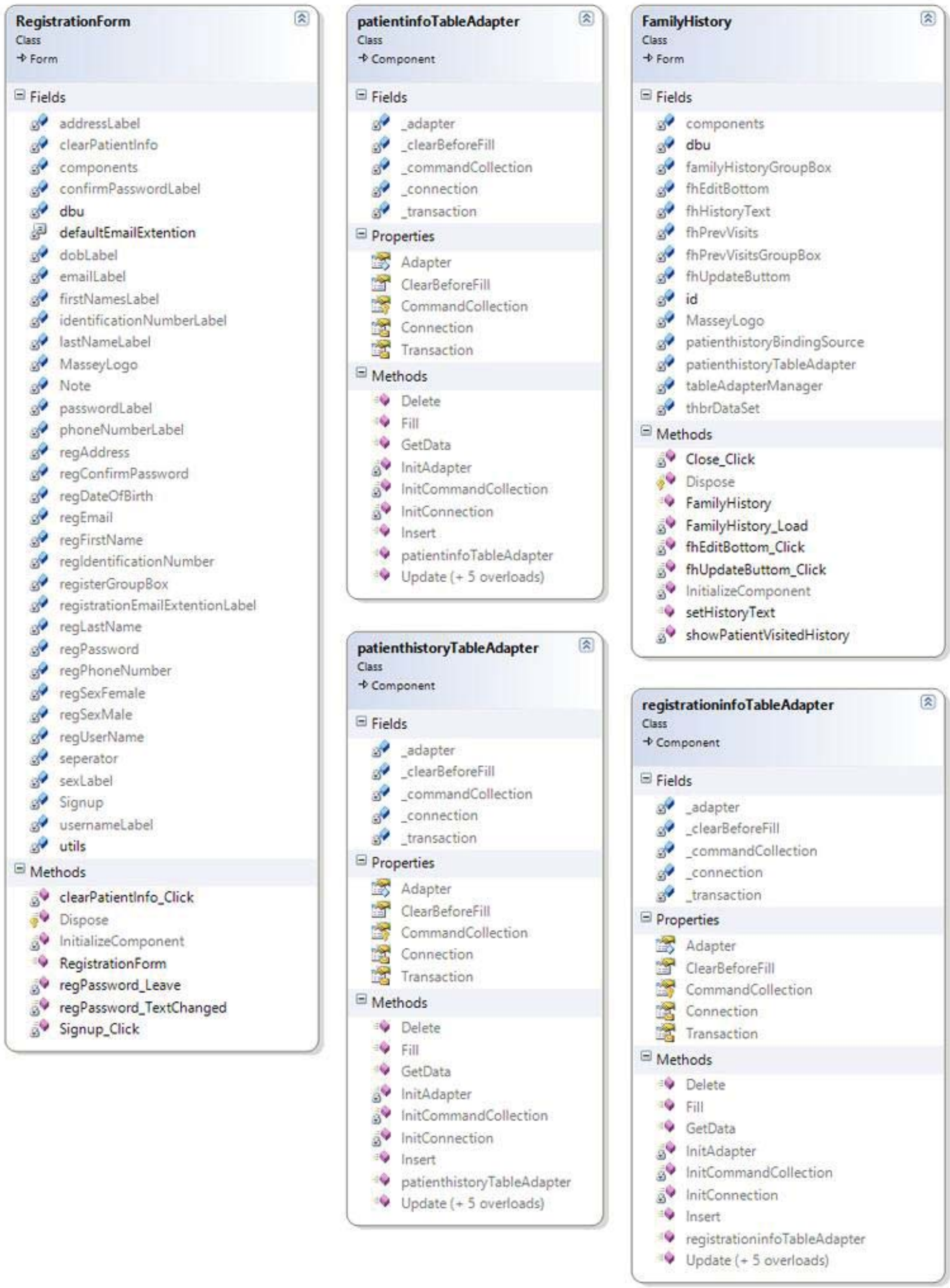
Database entity-relationship diagram



T-HBR software classes, methods and properties



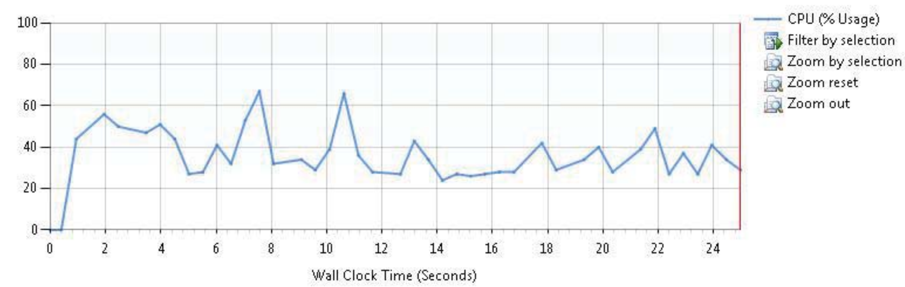

INIFile
Class
Fields
configurationFileName
filePath
Properties
FilePath
Methods
GetPrivateProfileString
INIFile
iniFileExists
Read
Write
WritePrivateProfileString
PdfWriter
Class
Fields
bytes
fontSize
inifile
leadSize
margin
mStreamID
mStreamLenID
mStreamStart
numPages
numXrefs
objectID
outFileStream
outputStreamPath
pageDepth
pageTreeID
pageWidth
pInsertPage
pXrefs
size
start_xref
yPos
Methods
DoText
EndPage
FileStreamWrite
PdfWriter
StartObject
StartPage
StorePage
Write
MySqlBackupRestore
Class
Fields
Construct_SQL_In_One_Line_From_Sa...
DropAndRecreateDatabase
DropAndRecreateTable
EncryptBackupFile
EncryptionKey
f
Filename
myDatabase
myOther
myPassword
myPort
myServer
MySQLConnectionString
myUser
progressBar1
Methods
Backup (+ 2 overloads)
MySqlBackupRestore (+ 1 overload)
NewProgressForm
Restore (+ 2 overloads)
XCryptEngine
Class
Fields
_algorithm
_he
_isHash
_isSymmetric
_key
_se
DefaultKey
Properties
Algorithm
IsHashAlgorithm
IsSymmetricAlgorithm
Key
Methods
Decrypt (+ 1 overload)
DestroyEngine
Encrypt (+ 1 overload)
formatKey
InitializeEngine (+ 1 overload)
XCryptEngine (+ 1 overload)
Nested Types
DatabaseUtils
Class
Fields
command
connection
databaseName
databasePassword
databaseUsername
inifile
MyConString
Reader
serverName
serverPort
utils
Methods
checkDatabaseExists
checkForExistanceUserID
checkLoginInfo
createDatabase
createHardwareDevicesTable
createPatientHistoryTable
createPatitientInfoTable
createRegistrationInfoTable
databaseBackup
databaseRestore
DatabaseUtils
getDeviceHardwareID
getDeviceHardwareSerialNumber
getDREmailByID
getDRFirstLastNamesByID
getDRsList
getLoginFirstLastnames
getPatientHistory
getPatientsID
getPatientsInfo
getPatientSpecificField
getPatientVisitsHistory
registerNewHardware
registerNewPatient
registerNewUser
updatePatientHistory
updatePatientHistoryDescription
CommunicationUtils
Class
Properties
Description
Name
Methods
CommunicationUtils
GetCOMPortsInfo


RegistrationForm
Class
Form
Fields
addressLabel
clearPatientInfo
components
confirmPasswordLabel
dbu
defaultEmailExtention
dobLabel
emailLabel
firstNamesLabel
identificationNumberLabel
lastNameLabel
MasseyLogo
Note
passwordLabel
phoneNumberLabel
regAddress
regConfirmPassword
regDateOfBirth
regEmail
regFirstName
regIdentificationNumber
registerGroupBox
registrationEmailExtentionLabel
regLastName
regPassword
regPhoneNumber
regSexFemale
regSexMale
regUserName
seperator
sexLabel
Signup
usernameLabel
utils
Methods
clearPatientInfo_Click
Dispose
InitializeComponent
RegistrationForm
regPassword_Leave
regPassword_TextChanged
Signup_Click
patientinfoTableAdapter
Class
Component
Fields
_adapter
_clearBeforeFill
_commandCollection
_connection
_transaction
Properties
Adapter
ClearBeforeFill
CommandCollection
Connection
Transaction
Methods
Delete
Fill
GetData
InitAdapter
InitCommandCollection
InitConnection
Insert
patientinfoTableAdapter
Update (+ 5 overloads)
patienthistoryTableAdapter
Class
Component
Fields
_adapter
_clearBeforeFill
_commandCollection
_connection
_transaction
Properties
Adapter
ClearBeforeFill
CommandCollection
Connection
Transaction
Methods
Delete
Fill
GetData
InitAdapter
InitCommandCollection
InitConnection
Insert
patienthistoryTableAdapter
Update (+ 5 overloads)
FamilyHistory
Class
Form
Fields
components
dbu
familyHistoryGroupBox
fhEditBottom
fhHistoryText
fhPrevVisits
fhPrevVisitsGroupBox
fhUpdateButtom
id
MasseyLogo
patienthistoryBindingSource
patienthistoryTableAdapter
tableAdapterManager
thbrDataSet
Methods
Close_Click
Dispose
FamilyHistory
FamilyHistory_Load
fhEditBottom_Click
fhUpdateButtom_Click
InitializeComponent
setHistoryText
showPatientVisitedHistory
registrationinfoTableAdapter
Class
Component
Fields
_adapter
_clearBeforeFill
_commandCollection
_connection
_transaction
Properties
Adapter
ClearBeforeFill
CommandCollection
Connection
Transaction
Methods
Delete
Fill
GetData
InitAdapter
InitCommandCollection
InitConnection
Insert
registrationinfoTableAdapter
Update (+ 5 overloads)

T-HBR memory profiling report

Memory Profiling Report

13,331,026 total bytes allocated



Notifications

Show All Code

View Guidance

Report

Show Trimmed Call Tree

Show Hot Lines

Compare Reports...

Export Report Data...

Save Analyzed Report...

Filter Report Data

Toggle Full Screen

Functions Allocating Most Memory

Functions with the highest exclusive bytes allocated

Name	Bytes %
ZedGraph.Symbol.Draw(class System.Drawing.Graphics,class ZedGraph.GraphPane,class ZedGraph.LineItem,fl...	25.84
System.Windows.Forms.Application.Run(class System.Windows.Forms.Form)	11.75
System.Drawing.Font.get_Name()	6.82
System.Data.Common.DbDataAdapter.Fill(class System.Data.DataTable)	3.66
System.Configuration.ApplicationSettingsBase.get_Item(string)	3.35

Types With Most Memory Allocated

Types with the hightest total number of bytes allocated

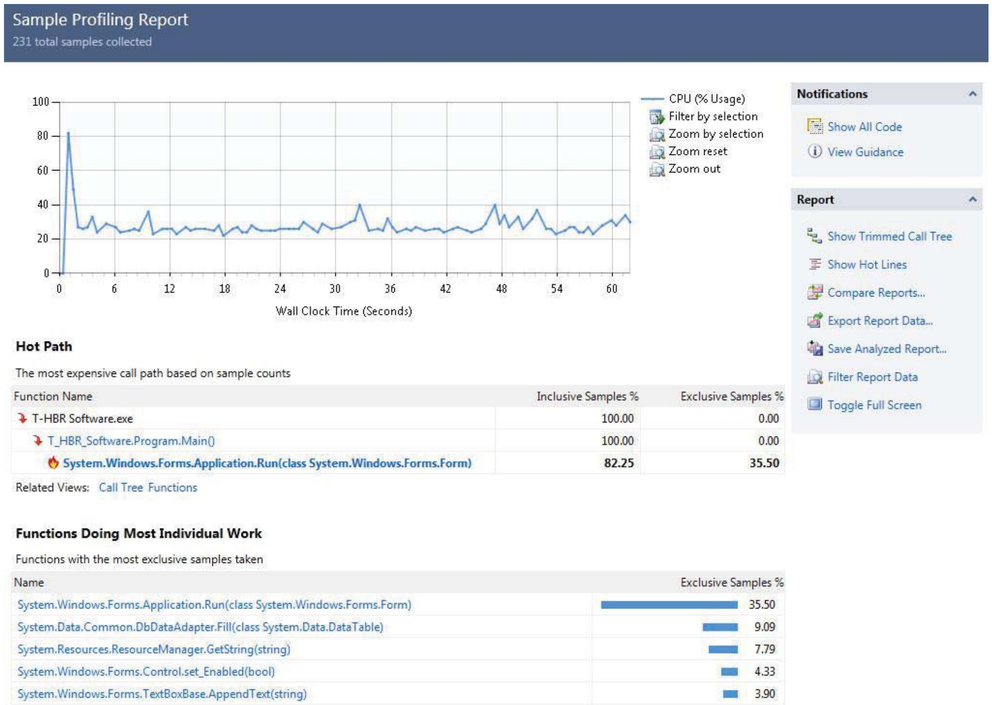
Name	Bytes %
System.Boolean[]	25.86
System.String	12.79
System.Char[]	8.58
System.Version	4.79
System.Byte[]	4.74

Types With Most Instances

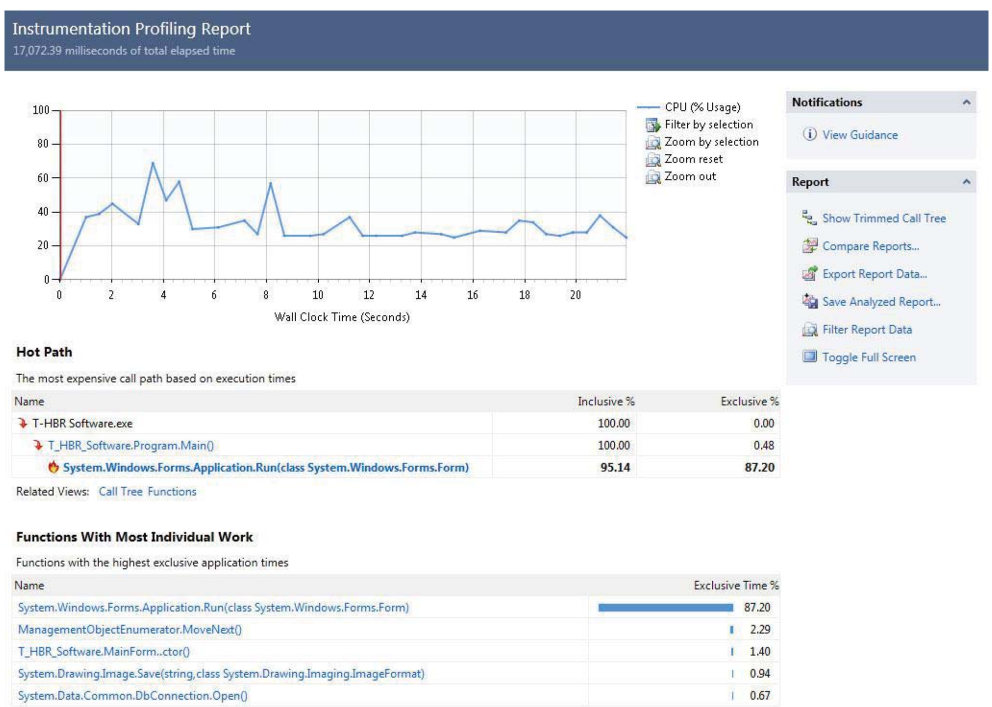
Types with the highest number of total allocations

Name	Instances %
System.String	17.66
System.Version	9.59
System.Char[]	6.74
System.Text.StringBuilder	3.48
System.Windows.Forms.LayoutEventArgs	3.04

T-HBR sample profiling report



T-HBR instrumentations profiling report



T-HBR software system requirement analysis

General information	Language / platform
Development environment	Visual Studio 2010
Language	C# with .Net 4
Platform	32/64 bit
Operating system	Windows XP/2000/Vista/7
Hardware type	**Minimum requirement**
CPU type	Pentium III
CPU speed	1 GHz
Memory	2 Gb
Disk Space	25 Mb
Display	VGA (1440 by 900 – 16 Bit)
External libraries name	**Download address**
ChilkatDotNet4.dll	http://www.chilkatsoft.com/
ZedGraph.dll	http://sourceforge.net/projects/zedgraph/
Pex and Moles unit testing	http://research.microsoft.com/
External software packages	**Download address**
MySQL-5 workbench + connectors	http://www.mysql.com
Adobe acrobat reader 6.x or higher	http://www.adobe.com

Micro-controller hardware requirement analysis

General information	Language / platform
Development environment	Arduino 0022 IDE
Language	Arduino C++
Platform	Windows 32/64 bit
Operating system	Windows XP/2000/Vista/7
External libraries	**Functionality**
avr/eeprom	EEPROM support
LString	Lightweight string support
LiquidCrystal	Supports LCD display
FatFs	Memory card support

Software metrics

Scope	Member	Maintainability Index	Cyclomatic Complexity	Depth of Inheritance	Class Coupling	Lines of Code
Type	CommunicationUtils	72	12	1	12	25
Type	INIFile	89	9	1	3	12
Type	ProcessConnection	74	3	1	3	13
Type	Blowfish	52	34	1	2	164
Type	BlowfishTables	79	2	1	1	6
Type	DatabaseUtils	57	79	1	13	348
Type	MySqlBackupRestore	47	60	1	25	237
Type	PdfPage	84	4	1	0	10
Type	PdfWriter	51	28	1	7	176
Type	Program	81	1	1	3	3
Type	Utils	60	48	1	38	178
Type	en	100	1	1	0	1
Type	TwofishBase	68	64	1	3	190
Type	TwofishBase.EncryptionDirection	100	0	1	0	0
Type	XCryptEngine	71	51	1	3	96
Type	XCryptEngine.AlgorithmType	100	0	1	0	0
Type	XCryptEngine.HashAlgorithmEngine	70	8	1	9	18
Type	XCryptEngine.HashAlgorithmEngine.EncodeMethodEnum	100	0	1	0	0
Type	XCryptEngine.SymmetricAlgorithmEngine	57	35	1	16	91
Type	XCryptEngine.SymmetricAlgorithmEngine.EncodeMethod Enum	100	0	1	0	0
Overal		**81**	**963**	**7**	**262**	**8391**

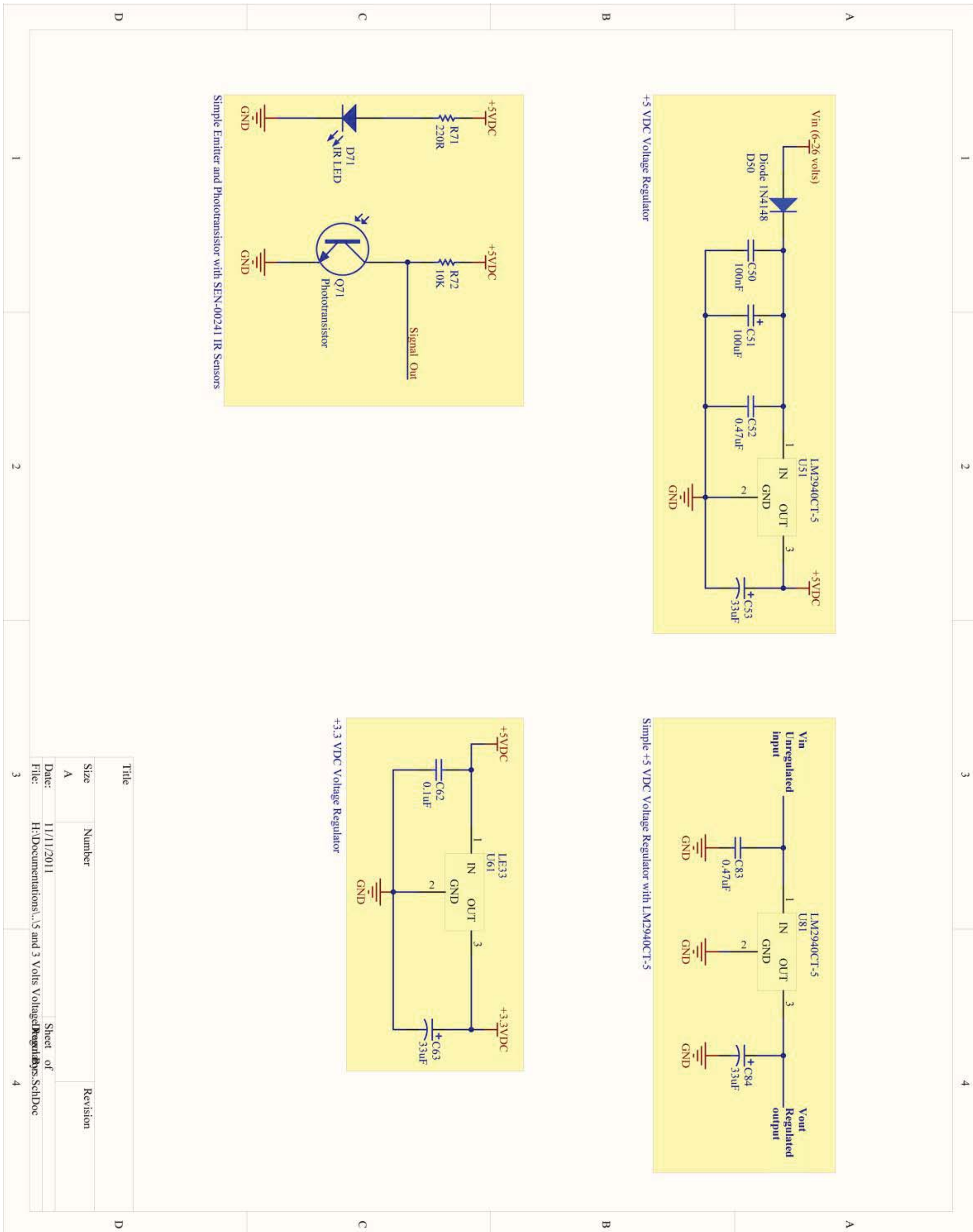
APPENDIX D – SENSORS DATA

Temperature and Heart Rate Data Log - Sample Size = 50

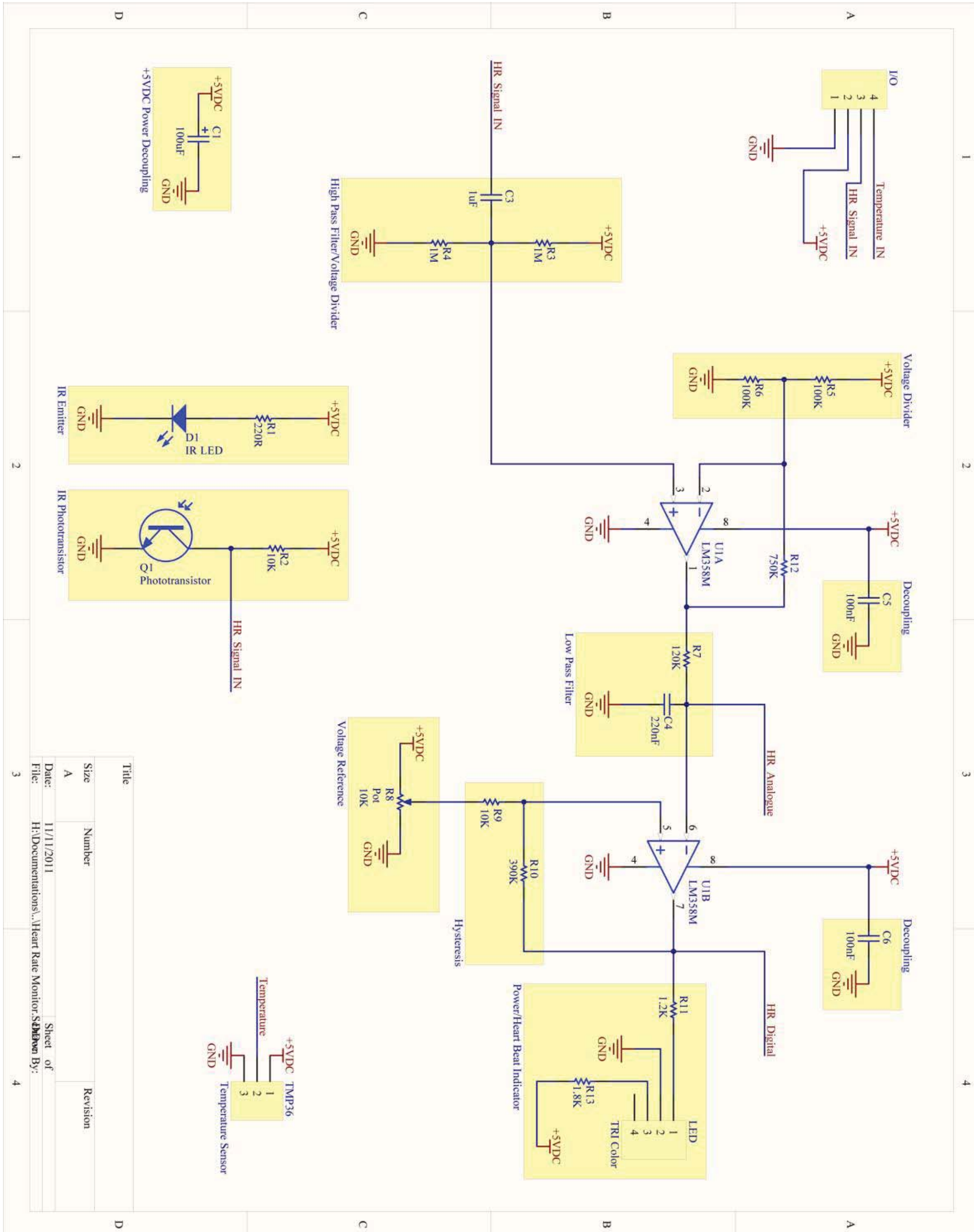
#	Prefered Name	Sensor readings	Ditigal Thermoeter	Difference C - B	MBT=0.64*Tcore + 0.36*Tskin	Difference C - E	Sensor Readings	Device Readings
1	Amir	28.30	35.72	7.42	34.98	0.74	70	70
2	Gerard	29.31	36.06	6.75	35.34	0.72	74	74
3	Phill	28.54	36.11	7.58	35.06	1.05	80	80
4	Brown	27.72	36.17	8.45	34.77	1.40	72	73
5	Taylor	29.14	36.17	7.03	35.28	0.89	82	82
6	Davies	27.66	36.39	8.73	34.75	1.64	74	75
7	Ivan	28.94	36.56	7.62	35.21	1.35	58	58
8	Chantel	27.56	36.56	9.00	34.71	1.84	64	65
9	Thomas	28.87	36.78	7.91	35.18	1.59	66	66
10	Hussein	27.95	36.78	8.83	34.85	1.92	72	72
11	Lee	27.14	36.89	9.75	34.56	2.33	82	82
12	Steve	27.33	36.94	9.62	34.63	2.32	70	71
13	Ahmed	28.44	37.00	8.56	35.03	1.97	76	77
14	Humaid	28.00	37.00	9.00	34.87	2.13	78	78
15	Thompson	30.29	37.00	6.71	35.70	1.30	70	70
16	White	30.67	37.11	6.44	35.83	1.28	78	78
17	Hughes	30.66	37.17	6.50	35.83	1.34	80	80
18	John	27.68	35.94	8.27	34.75	1.19	62	62
19	Green	28.68	36.22	7.54	35.12	1.11	68	68
20	Hall	27.27	36.33	9.06	34.61	1.72	56	57
21	Wood	31.76	36.50	4.74	36.23	0.27	84	84
22	Richard	29.76	36.61	6.85	35.50	1.11	68	69
23	Lewis	31.17	36.61	5.44	36.01	0.60	78	79
24	Martin	28.10	36.67	8.57	34.91	1.76	76	76
25	Linda	28.16	36.72	8.57	34.93	1.80	80	81
26	Carol	31.40	36.78	5.37	36.10	0.68	72	73
27	Janet	29.95	36.78	6.82	35.57	1.20	64	64
28	Jennifer	31.21	36.78	5.56	36.03	0.75	68	69
29	Lin	32.10	36.78	4.67	36.35	0.43	56	57
30	Xin	30.46	36.83	6.37	35.76	1.08	80	80
31	Cooper	28.57	36.89	8.32	35.08	1.81	74	74
32	Morris	32.82	37.06	4.24	36.60	0.45	58	59
33	Kate	32.72	37.06	4.34	36.57	0.49	64	65
34	Fiona	28.54	37.11	8.57	35.06	2.05	70	70
35	King	31.81	37.17	5.35	36.24	0.92	76	76
36	Watson	32.15	37.33	5.18	36.37	0.97	78	77
37	Baker	29.72	36.39	6.67	35.49	0.90	70	70
38	Harrison	29.88	36.56	6.68	35.55	1.01	72	73
39	Morgan	29.08	36.56	7.48	35.26	1.30	74	74
40	Mohammad	26.79	36.67	9.88	34.43	2.23	78	78
41	Hamed	27.32	36.67	9.34	34.63	2.04	64	64
42	Allen	28.14	36.67	8.53	34.92	1.75	78	78
43	Mitchell	31.76	36.78	5.02	36.22	0.55	70	71
44	James	29.92	37.06	7.14	35.56	1.50	78	78
45	Andrew	30.85	37.39	6.54	35.89	1.49	62	63
46	Phillip	28.92	36.44	7.53	35.20	1.24	60	61
47	Lee	31.61	36.56	4.95	36.17	0.39	62	62
48	Venessa	28.99	37.00	8.01	35.23	1.77	86	86
49	Parker	28.10	37.06	8.96	34.91	2.15	82	82
50	Davis	27.67	36.94	9.27	34.75	2.19	82	83
	Min:	26.79	35.72	4.24	34.43	0.27	56	57
	Max:	32.82	37.39	9.88	36.60	2.33	86	86
	Median:	28.96	36.78	7.50	35.22	1.30	72	73
	Average:	29.39	36.71	7.31	35.37	1.33	72	72

APPENDIX E – HARDWARE

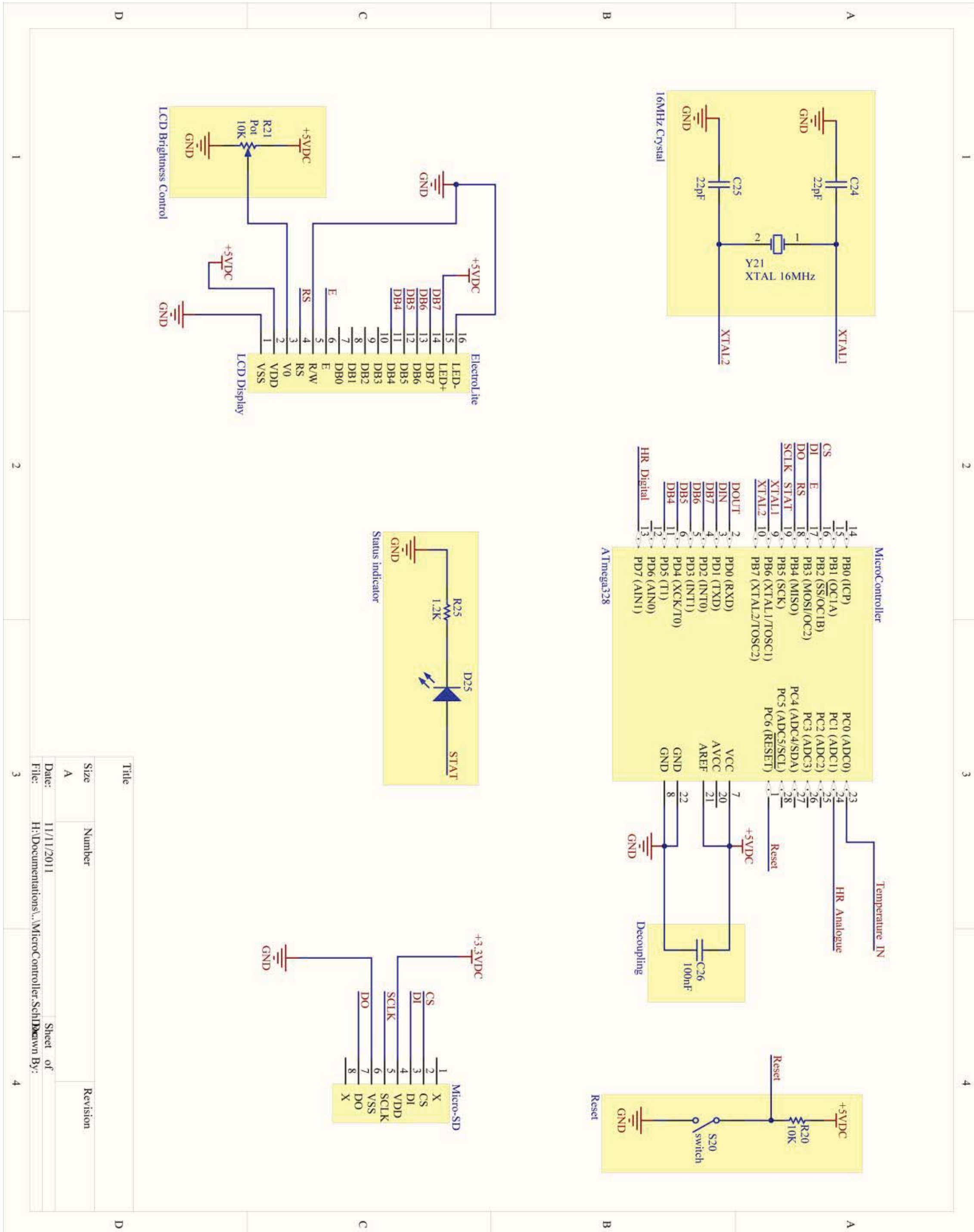
5V and 3.3V voltage regulators schematic



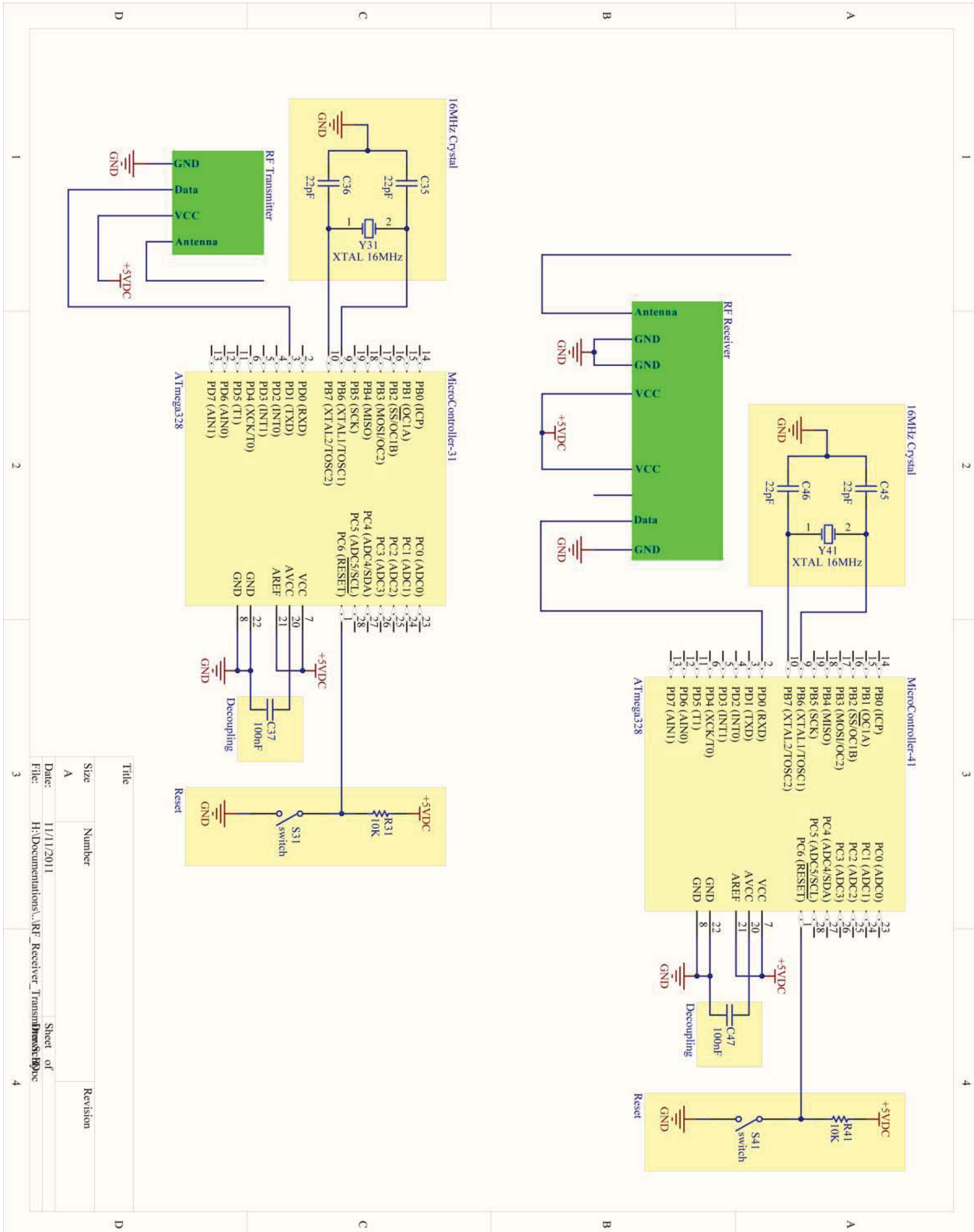
Heart rate sensor schematic



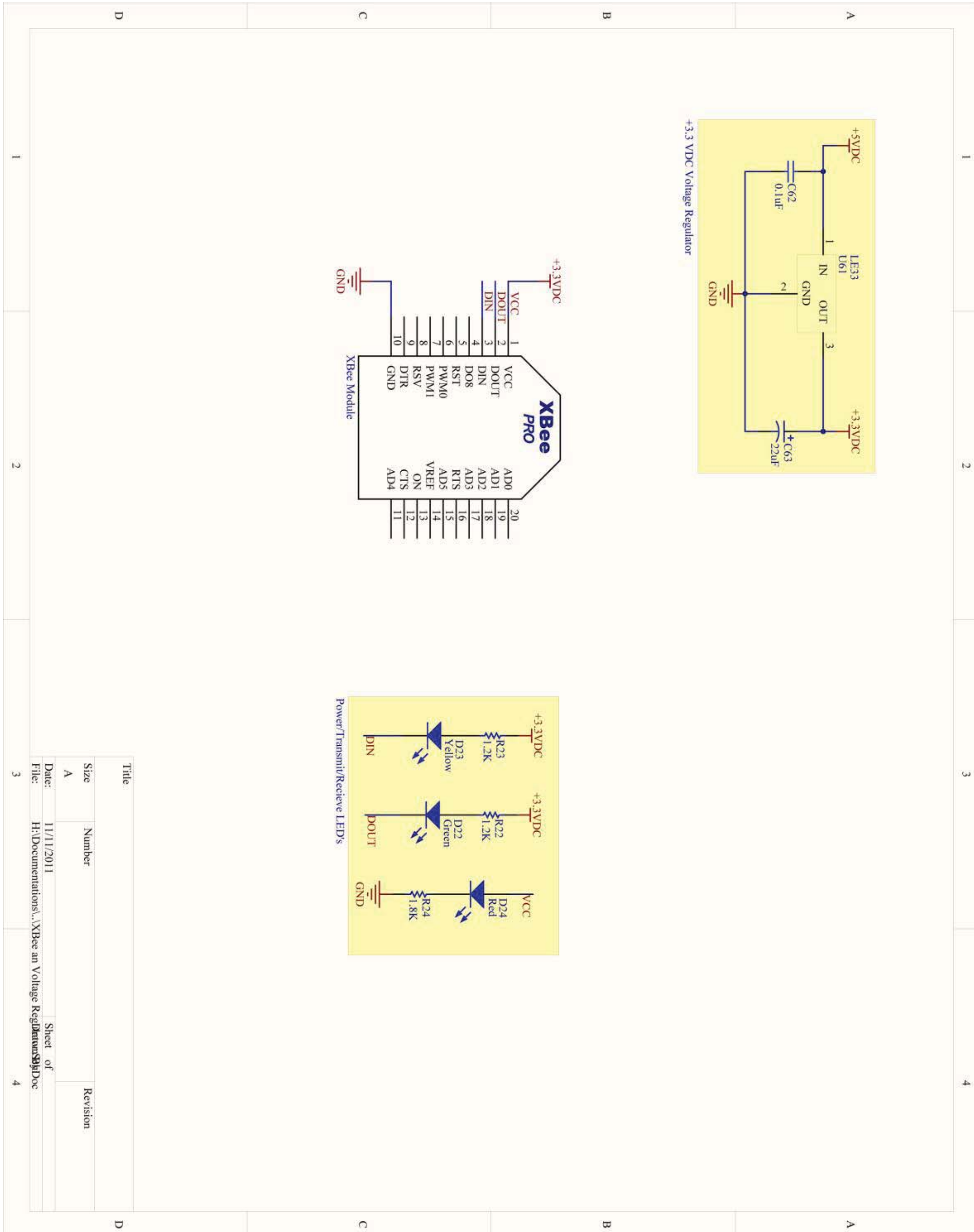
Stand-alone Arduino schematic



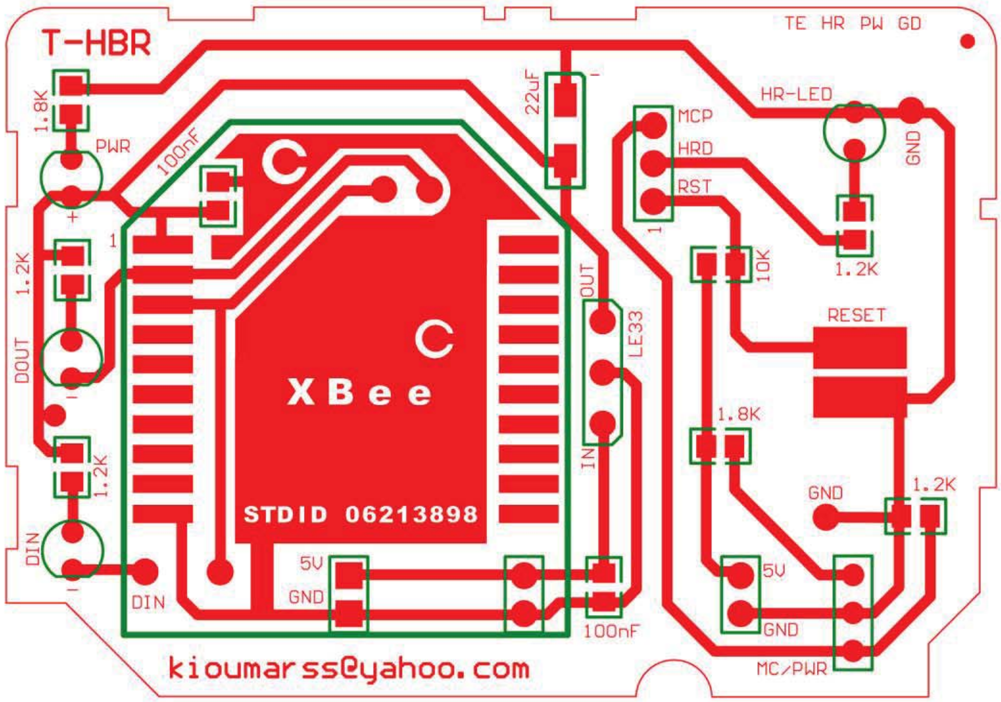
RF modules connections to Arduino schematic

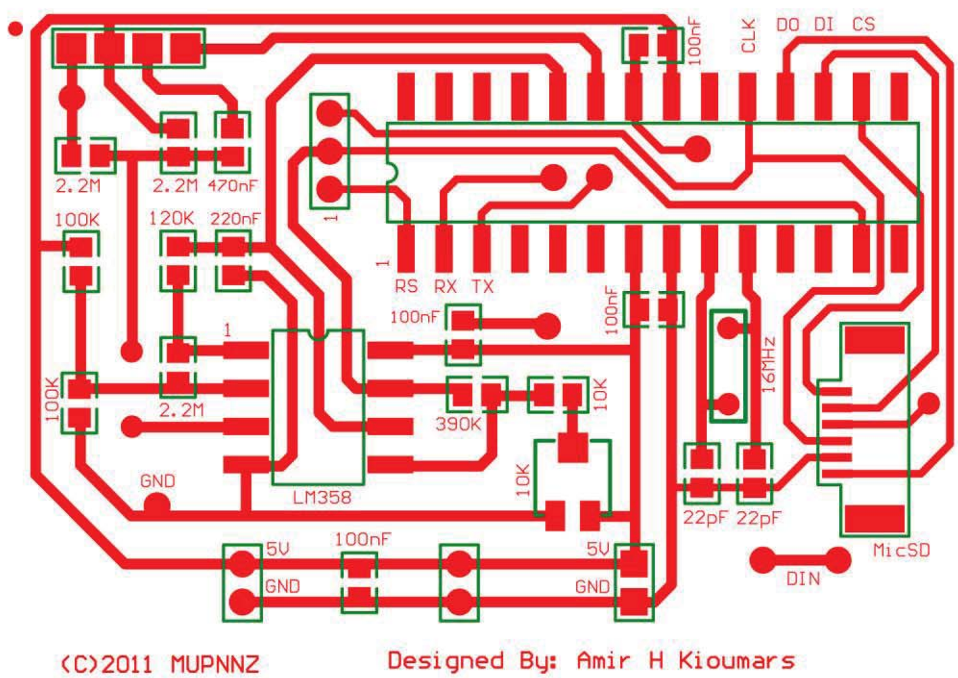


XBee Arduino connections schematic



Hardware device PCB design





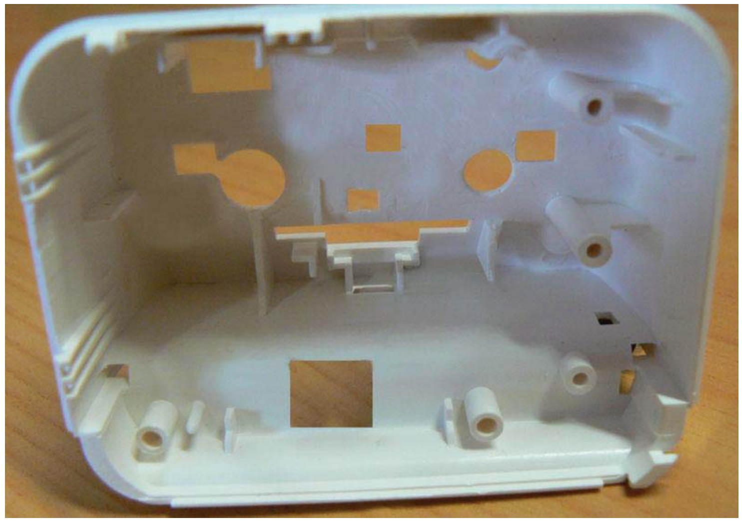
Top PCB (top layer) – Bottom PCB (bottom layer)

APPENDIX F – HARDWARE PARTS/COST ANALYSIS

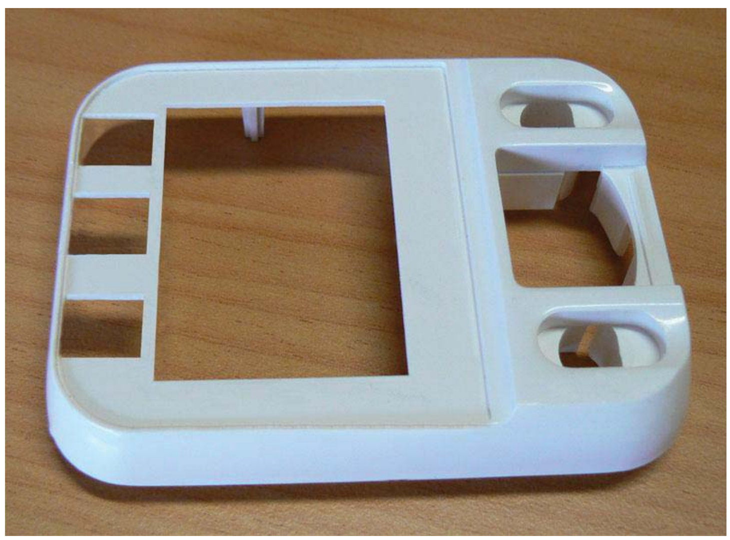
Component type	Value	Quantity	Unit Price	Total price
XBee radio	Series2 Pro	1	$65.0	$65.0
Super bright LED	9000 MCD	4	$1.00	$4.00
Tri-Color LED	9000 MCD	1	$3.00	$3.00
Voltage regulator	LE33	1	$0.90	$0.90
ATmega chip	328 family	1	$7.50	$7.50
Crystal	16MHz	1	$0.75	$0.75
Dual op-amp	LM358	1	$0.65	$0.65
Micro-SD socket	2.65mm/8pins	1	$2.90	$2.90
Temperature sensor	TMP36	1	$2.41	$2.41
IR Emitter	950nM	1	$1.50	$1.50
IR Phototransistor		1	$1.50	$1.50
Li-ion battery 3.7V	1000mA	1	$15.0	$15.0
Charger	Li-Po	1	$35.0	$35.0
Diode	5A	1	$0.12	$0.12
DC connector		1	$2.50	$2.50
Resistors	2.2M	3	$0.10	$0.30
	100K	2	$0.19	$0.38
	120K	1	$0.34	$0.34
	10K	2	$0.18	$0.36
	10K Pot	1	$1.83	$1.83
	1.2K	3	$0.17	$0.51
	1.8K	2	$0.25	$0.50
Capacitors	100nF	5	$0.16	$0.80
	22uF	1	$0.18	$0.18
	470nF	1	$0.26	$0.26
	220nF	1	$0.22	$0.22
	22pF	2	$0.18	$0.36
PCB, wires, case		2	$10.0	$20.0

Total Cost:	**$178.77**

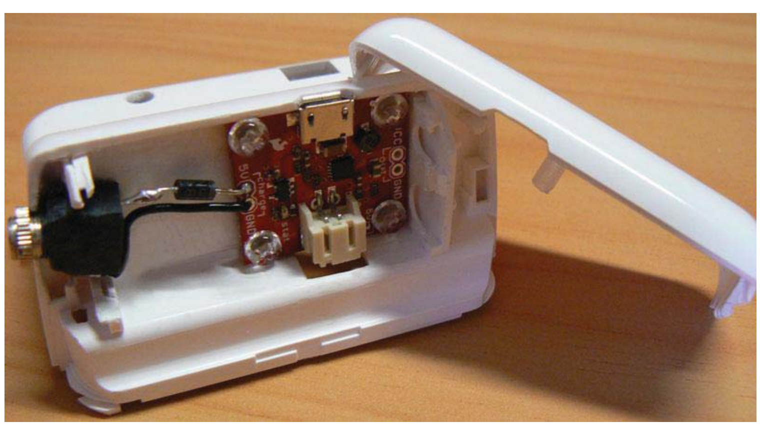
APPENDIX G – HARDWARE DEVICE ASSEMBLY



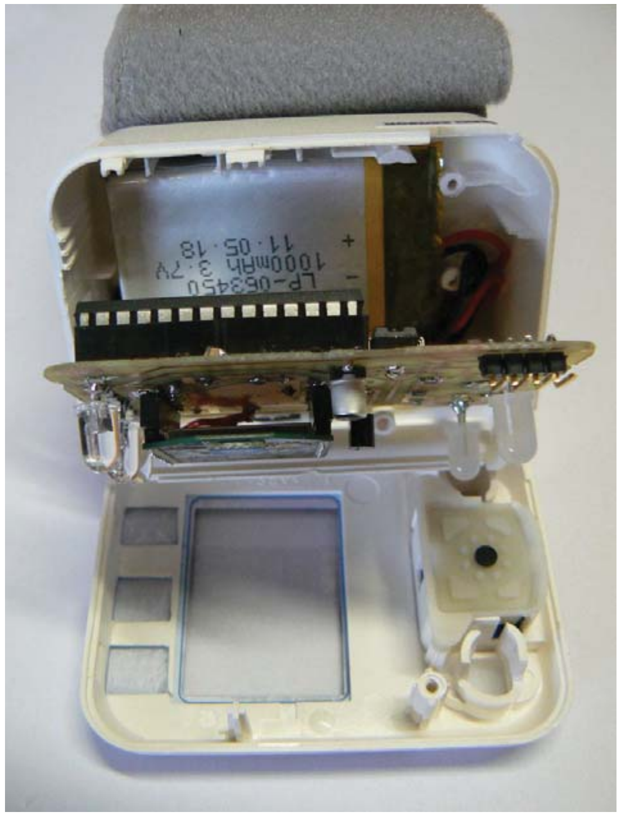
Box inside



Front cover



Booster – regulator



Placing the Li-ion battery

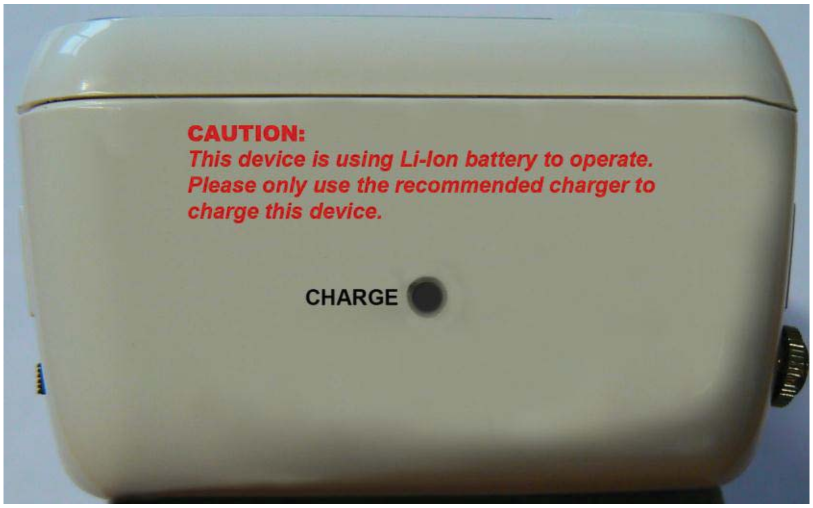
Top layer

DC input to booster-regulator

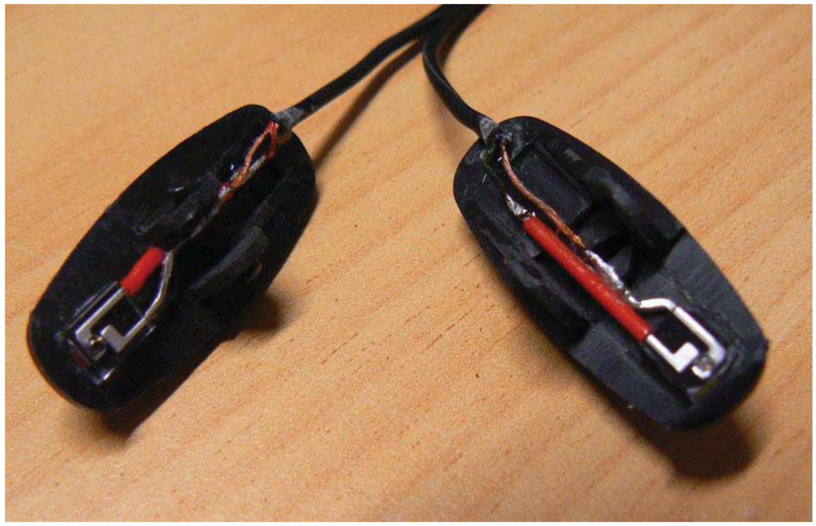
Micro-SD card connector and power button

Micro-USB input

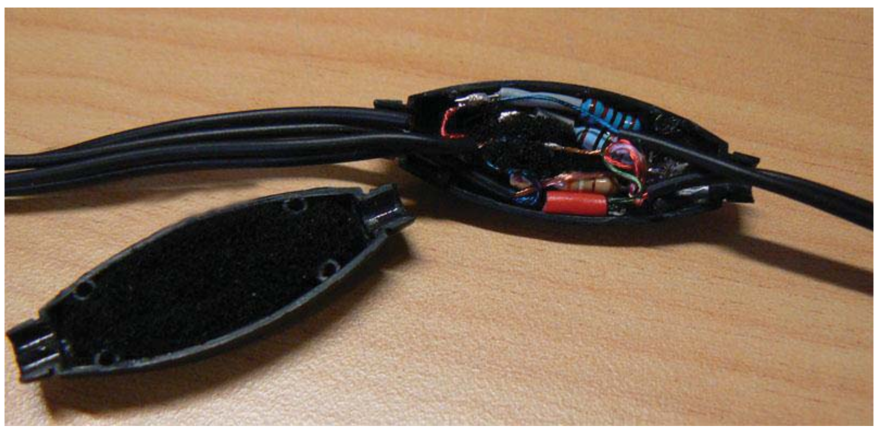
Temperature and heart rate sensors connector



Charge LED



IR emitter and phototransistor

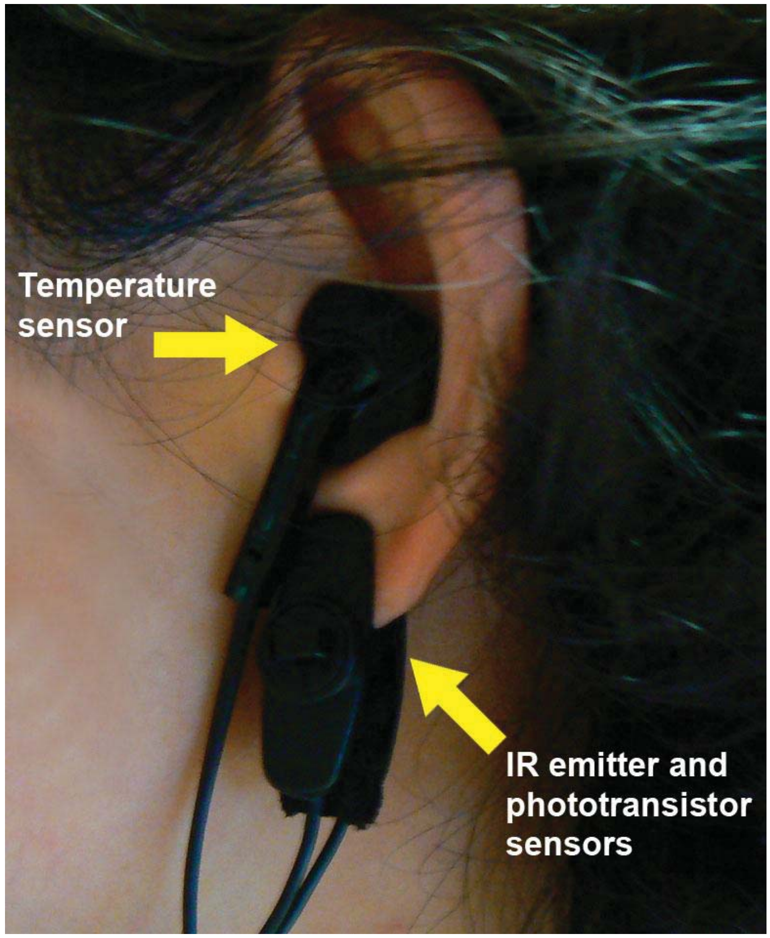


IR emitter and phototransistor resistors + power LED

TMP36 and IR sensors assembly

Complete sensor device

Sensor packaging

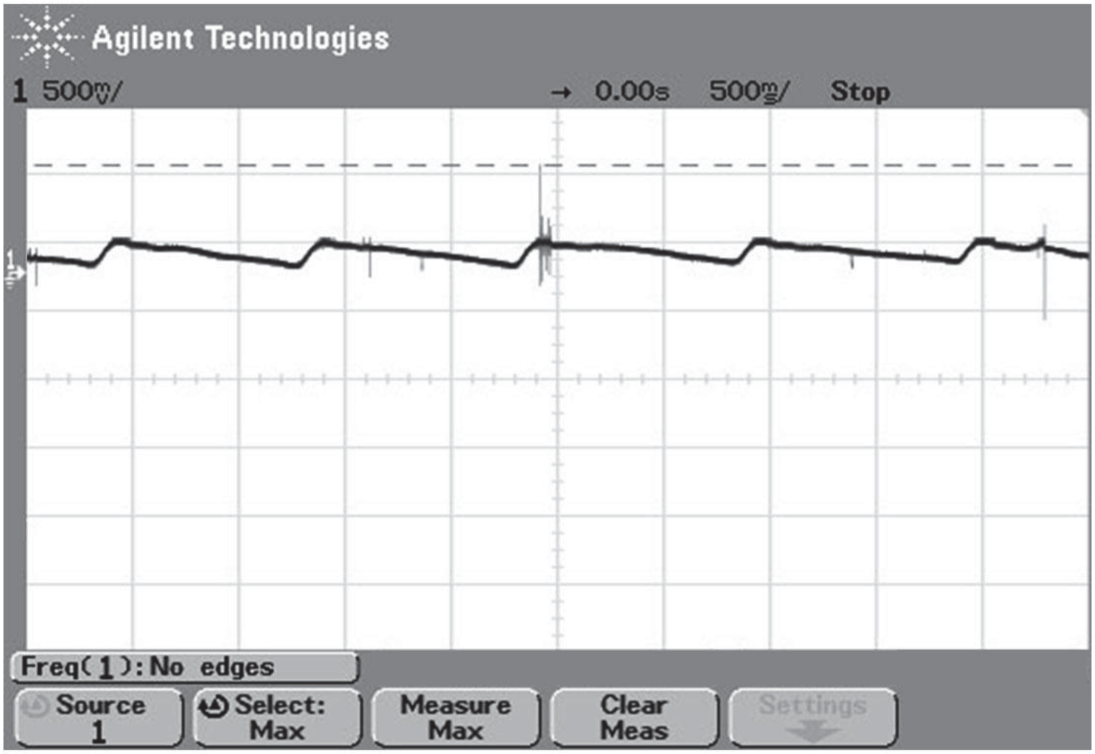


Temperature and heart rate sensors

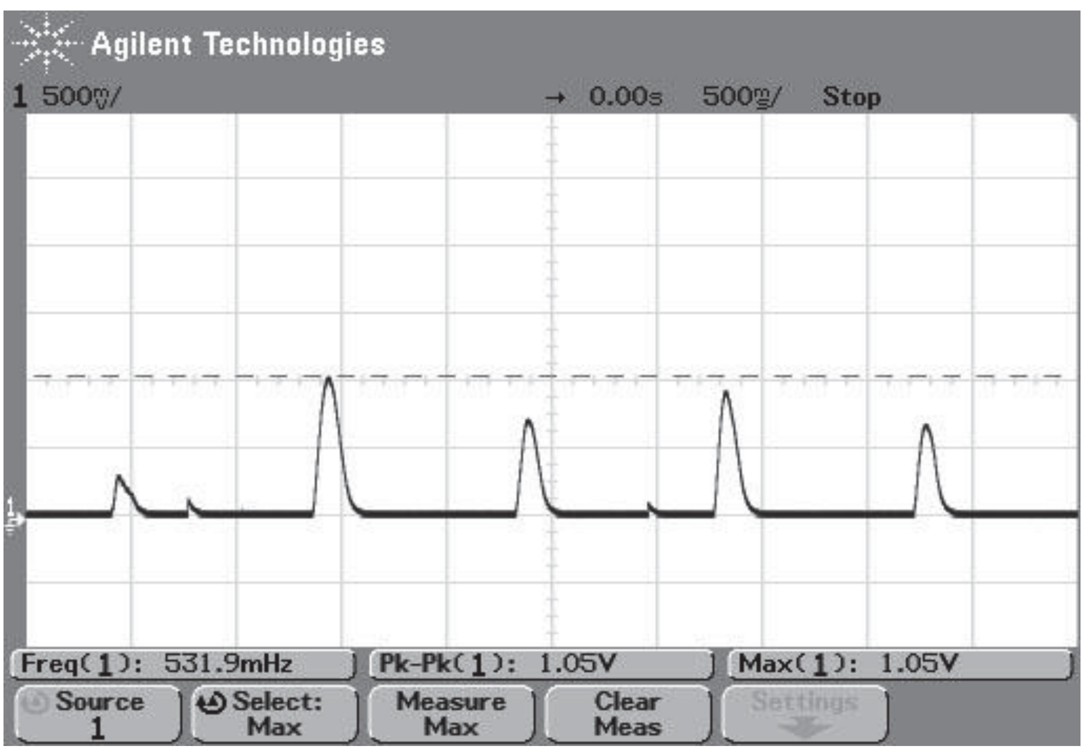
Hardware device wrapped around the wrist

Using the temperature, heart rate and hardware device

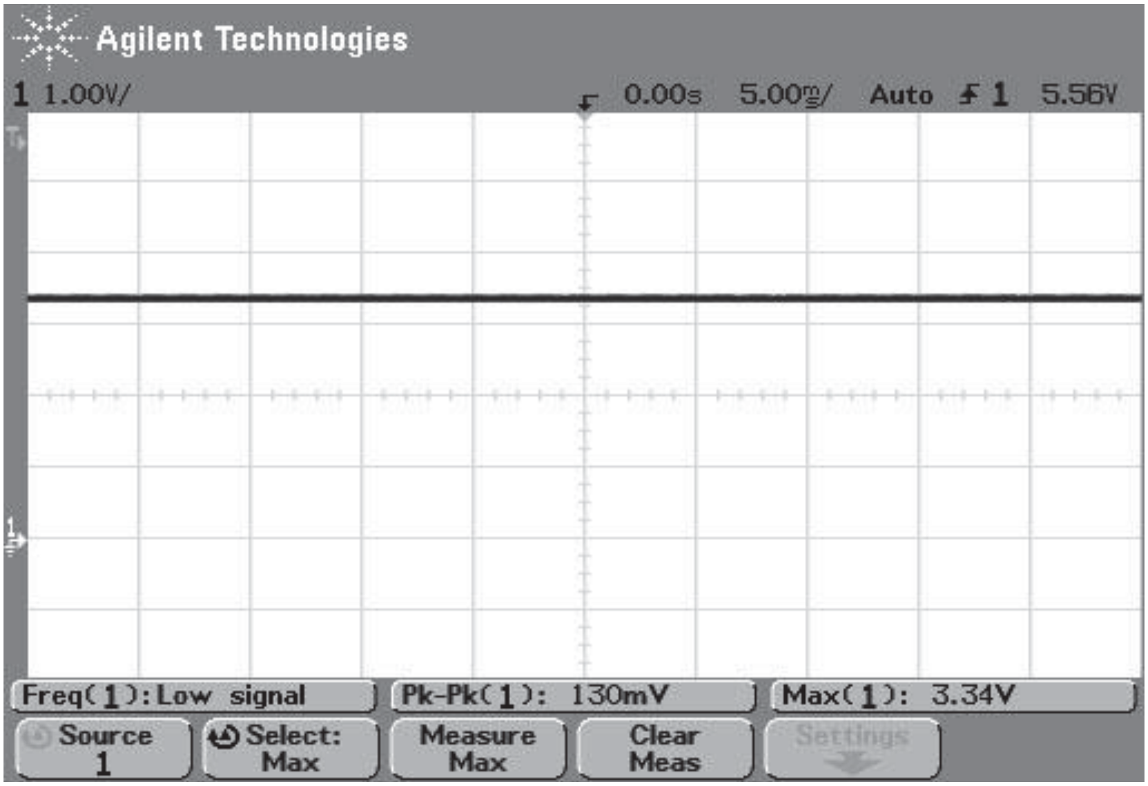
APPENDIX H – HARDWARE TEST REAULTS



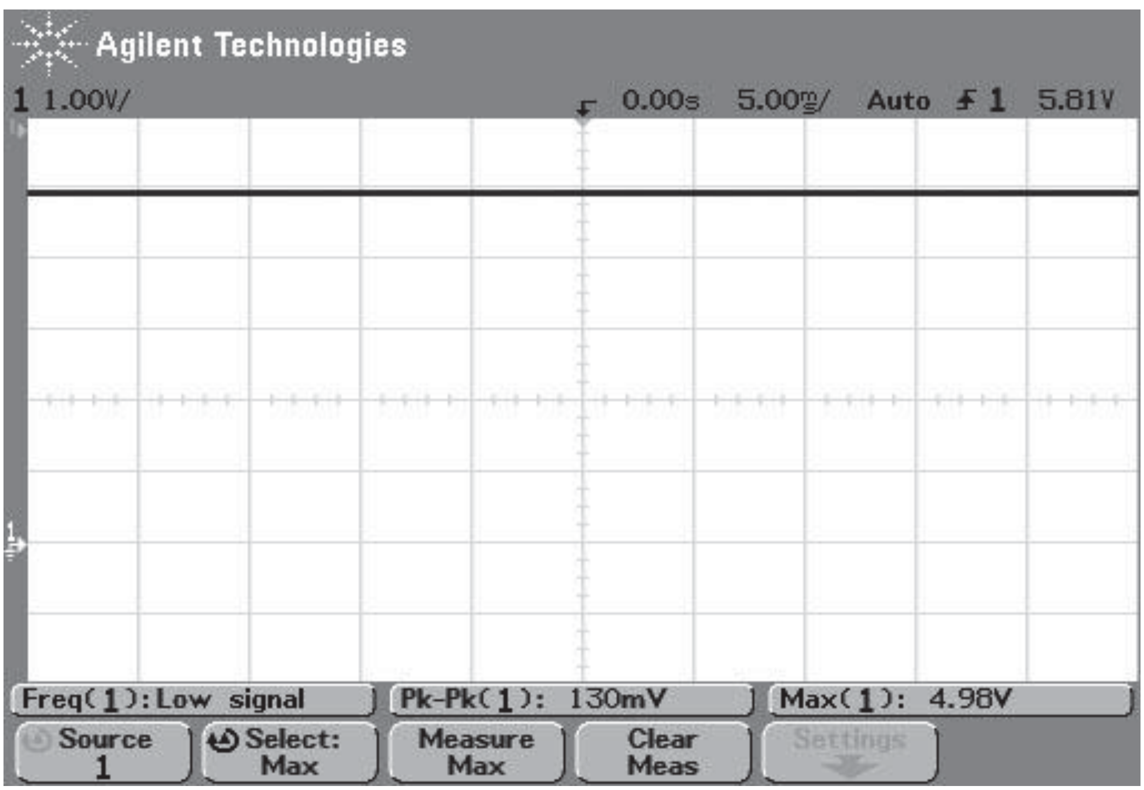
Normal signals



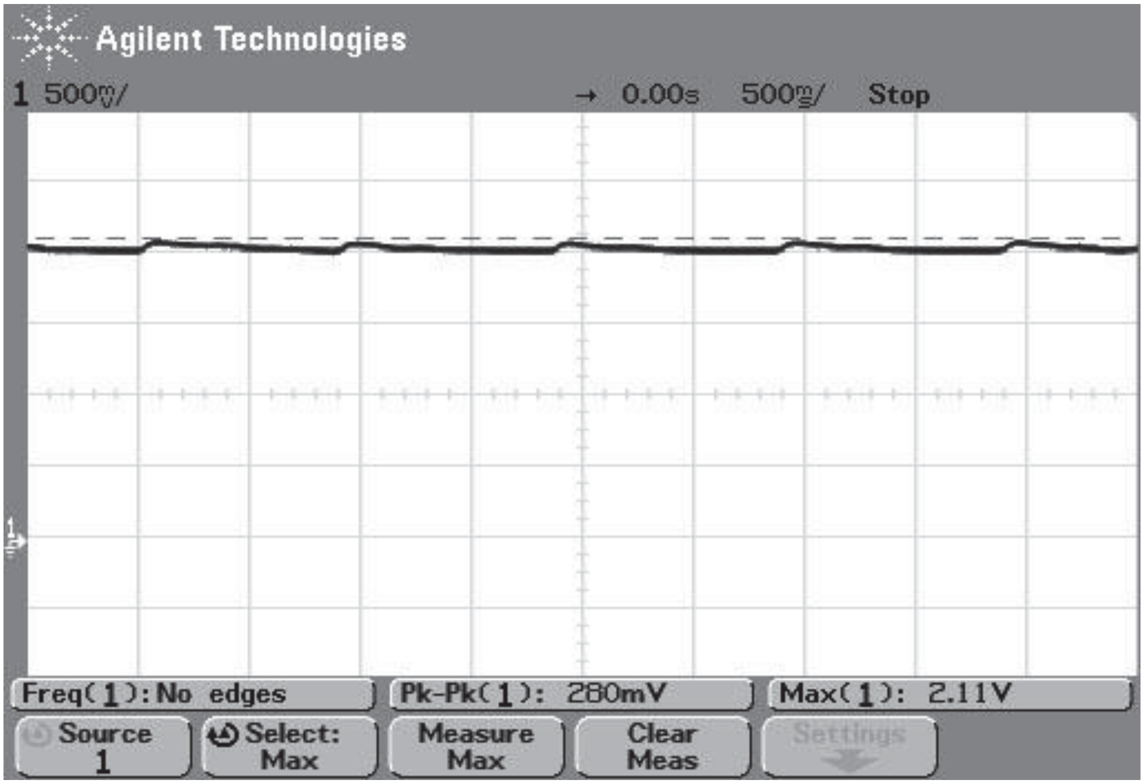
Signals amplification



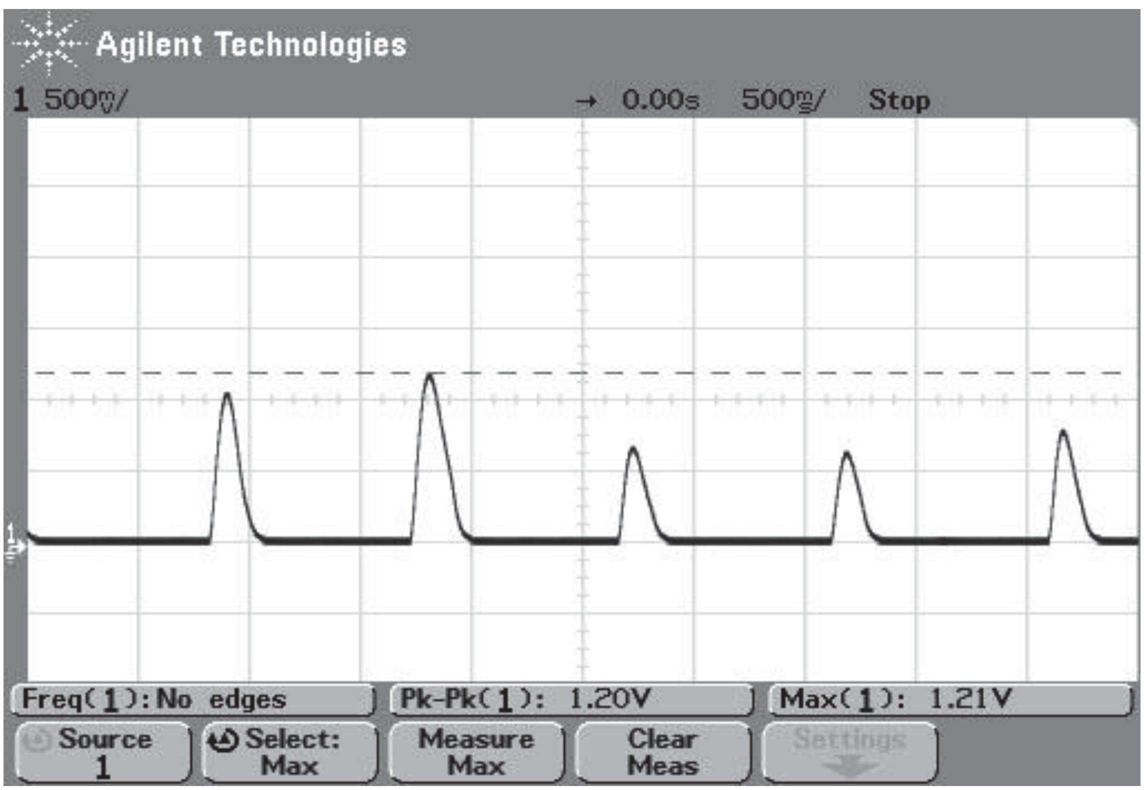
LE33 3.3V voltage regulator output



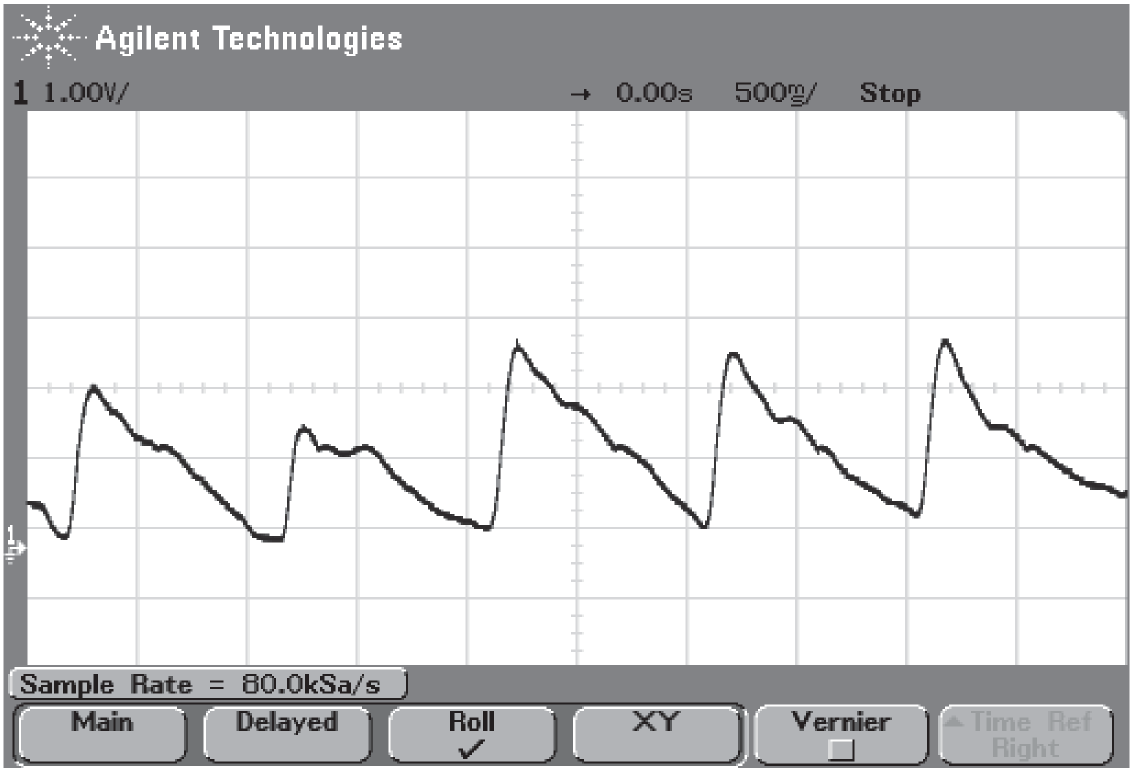
Power cell charger - booster voltage output



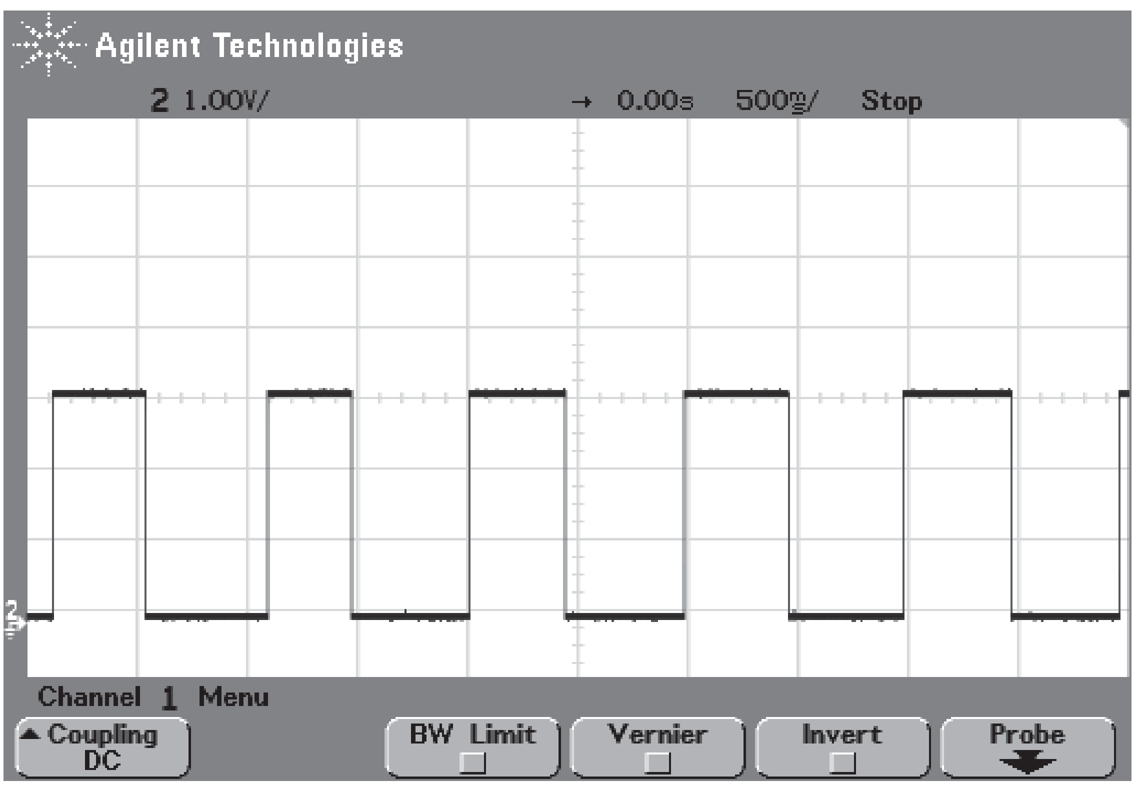
High-pass filter output



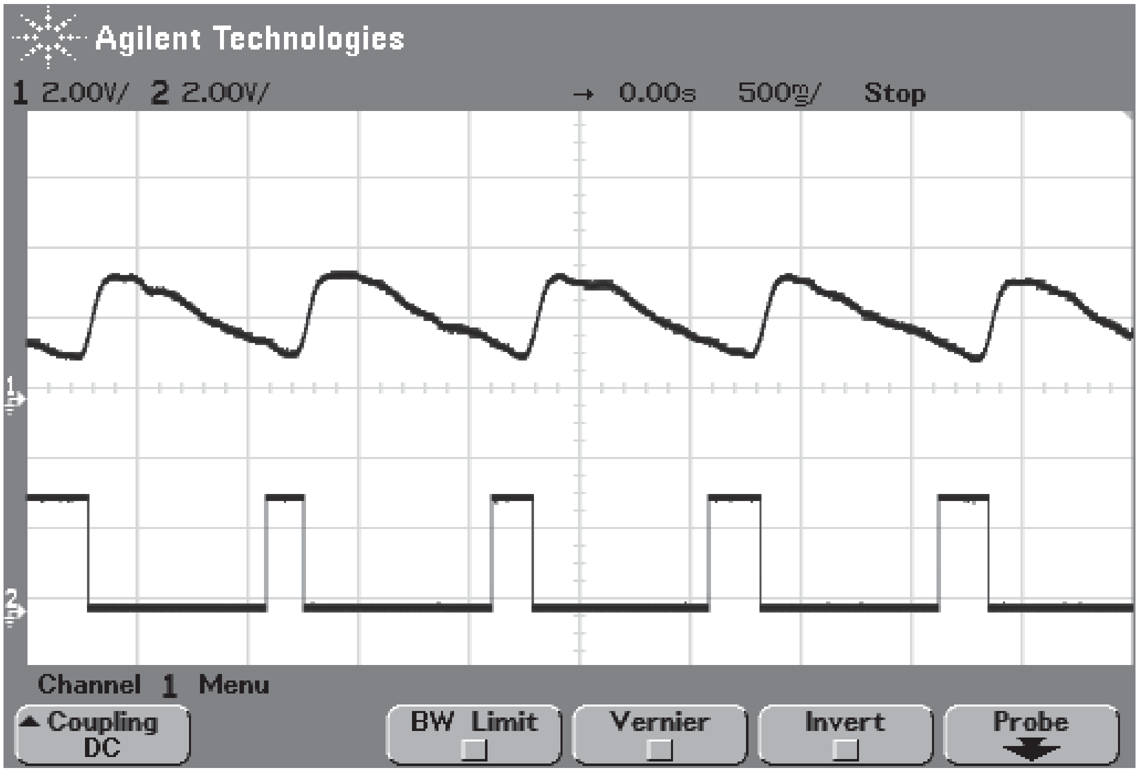
Low-pass filter output



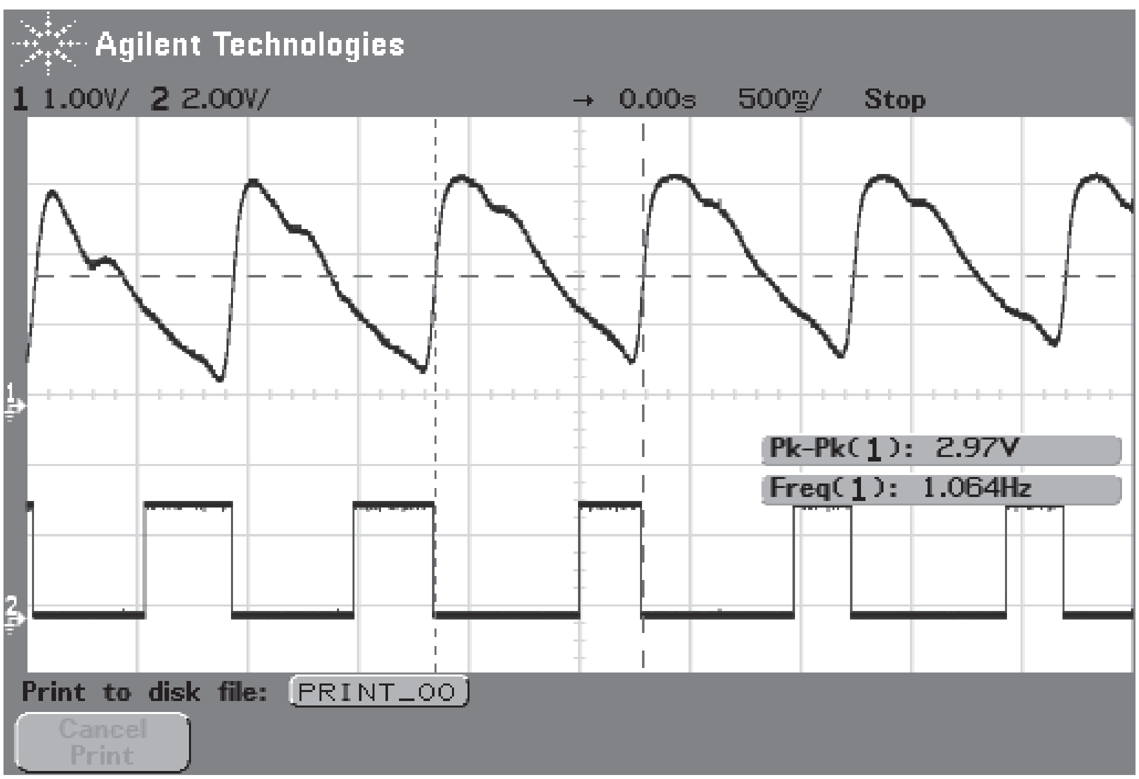
Heart rate sensor analogue output



Heart rate sensor digital output



Heart rate sensor analogue and digital output



Heart rate signals frequency

APPENDIX I – DATASHEETS[1]

ATmel/ATmega chip

Features

- High Performance, Low Power Atmel® AVR® 8-Bit Microcontroller
- Advanced RISC Architecture
  - 131 Powerful Instructions – Most Single Clock Cycle Execution
  - 32 x 8 General Purpose Working Registers
  - Fully Static Operation
  - Up to 20 MIPS Throughput at 20 MHz
  - On-chip 2-cycle Multiplier
- High Endurance Non-volatile Memory Segments
  - 4/8/16KBytes of In-System Self-Programmable Flash progam memory
  - 256/512/512Bytes EEPROM
  - 512/1K/1KBytes Internal SRAM
  - Write/Erase Cycles: 10,000 Flash/100,000 EEPROM
  - Data retention: 20 years at 85°C/100 years at 25°C(1)
  - Optional Boot Code Section with Independent Lock Bits
    In-System Programming by On-chip Boot Program
    True Read-While-Write Operation
  - Programming Lock for Software Security
- QTouch® library support
  - Capacitive touch buttons, sliders and wheels
  - QTouch and QMatrix acquisition
  - Up to 64 sense channels
- Peripheral Features
  - Two 8-bit Timer/Counters with Separate Prescaler and Compare Mode
  - One 16-bit Timer/Counter with Separate Prescaler, Compare Mode, and Capture Mode
  - Real Time Counter with Separate Oscillator
  - Six PWM Channels
  - 8-channel 10-bit ADC in TQFP and QFN/MLF package
    Temperature Measurement
  - 6-channel 10-bit ADC in PDIP Package
    Temperature Measurement
  - Programmable Serial USART
  - Master/Slave SPI Serial Interface
  - Byte-oriented 2-wire Serial Interface (Philips I^{2}C compatible)
  - Programmable Watchdog Timer with Separate On-chip Oscillator
  - On-chip Analog Comparator
  - Interrupt and Wake-up on Pin Change
- Special Microcontroller Features
  - Power-on Reset and Programmable Brown-out Detection
  - Internal Calibrated Oscillator
  - External and Internal Interrupt Sources
  - Six Sleep Modes: Idle, ADC Noise Reduction, Power-save, Power-down, Standby, and Extended Standby
- I/O and Packages
  - 23 Programmable I/O Lines
  - 28-pin PDIP, 32-lead TQFP, 28-pad QFN/MLF and 32-pad QFN/MLF
- Operating Voltage:
  - 1.8 - 5.5V for ATmega48P/88P/168PV
  - 2.7 - 5.5V for ATmega48P/88P/168P
- Temperature Range:
  - -40°C to 85°C
- Speed Grade:
  - ATmega48P/88P/168PV: 0 - 4MHz @ 1.8 - 5.5V, 0 - 10MHz @ 2.7 - 5.5V
  - ATmega48P/88P/168P: 0 - 10MHz @ 2.7 - 5.5V, 0 - 20MHz @ 4.5 - 5.5V
- Low Power Consumption at 1MHz, 1.8V, 25°C:
  - Active Mode: 0.3mA
  - Power-down Mode: 0.1µA
  - Power-save Mode: 0.8µA (Including 32kHz RTC)

Note: 1. See "Data Retention" on page 8 for details.

8-bit Atmel Microcontroller with 4/8/16K Bytes In-System Programmable Flash

ATmega48P/V
ATmega88P/V
ATmega168P/V

Rev. 8025M–AVR–6/11

[1] This complete components datasheets can be found on nz.element14.com

TMP36 temperature sensor

ANALOG DEVICES

Low Voltage Temperature Sensors

TMP35/TMP36/TMP37

FEATURES

Low voltage operation (2.7 V to 5.5 V)
Calibrated directly in °C
10 mV/°C scale factor (20 mV/°C on TMP37)
±2°C accuracy over temperature (typ)
±0.5°C linearity (typ)
Stable with large capacitive loads
Specified −40°C to +125°C, operation to +150°C
Less than 50 μA quiescent current
Shutdown current 0.5 μA max
Low self-heating
Qualified for automotive applications

APPLICATIONS

Environmental control systems
Thermal protection
Industrial process control
Fire alarms
Power system monitors
CPU thermal management

GENERAL DESCRIPTION

The TMP35/TMP36/TMP37 are low voltage, precision centigrade temperature sensors. They provide a voltage output that is linearly proportional to the Celsius (centigrade) temperature. The TMP35/ TMP36/TMP37 do not require any external calibration to provide typical accuracies of ±1°C at +25°C and ±2°C over the −40°C to +125°C temperature range.

The low output impedance of the TMP35/TMP36/TMP37 and its linear output and precise calibration simplify interfacing to temperature control circuitry and ADCs. All three devices are intended for single-supply operation from 2.7 V to 5.5 V maximum. The supply current runs well below 50 μA, providing very low self-heating—less than 0.1°C in still air. In addition, a shutdown function is provided to cut the supply current to less than 0.5 μA.

The TMP35 is functionally compatible with the LM35/LM45 and provides a 250 mV output at 25°C. The TMP35 reads temperatures from 10°C to 125°C. The TMP36 is specified from −40°C to +125°C, provides a 750 mV output at 25°C, and operates to 125°C from a single 2.7 V supply. The TMP36 is functionally compatible with the LM50. Both the TMP35 and TMP36 have an output scale factor of 10 mV/°C.

FUNCTIONAL BLOCK DIAGRAM

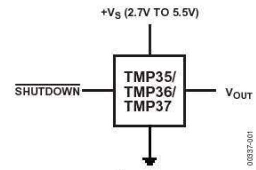


Figure 1.

PIN CONFIGURATIONS

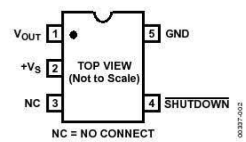


Figure 2. RJ-5 (SOT-23)

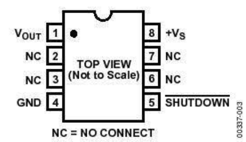


Figure 3. R-8 (SOIC_N)

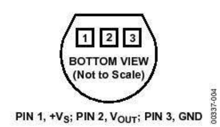


Figure 4. T-3 (TO-92)

The TMP37 is intended for applications over the range of 5°C to 100°C and provides an output scale factor of 20 mV/°C. The TMP37 provides a 500 mV output at 25°C. Operation extends to 150°C with reduced accuracy for all devices when operating from a 5 V supply.

The TMP35/TMP36/TMP37 are available in low cost 3-lead TO-92, 8-lead SOIC_N, and 5-lead SOT-23 surface-mount packages.

One Technology Way, P.O. Box 9106, Norwood, MA 02062-9106, U.S.A.
Tel: 781.329.4700 www.analog.com
Fax: 781.461.3113

SEN-00241 IR Photo-transistor

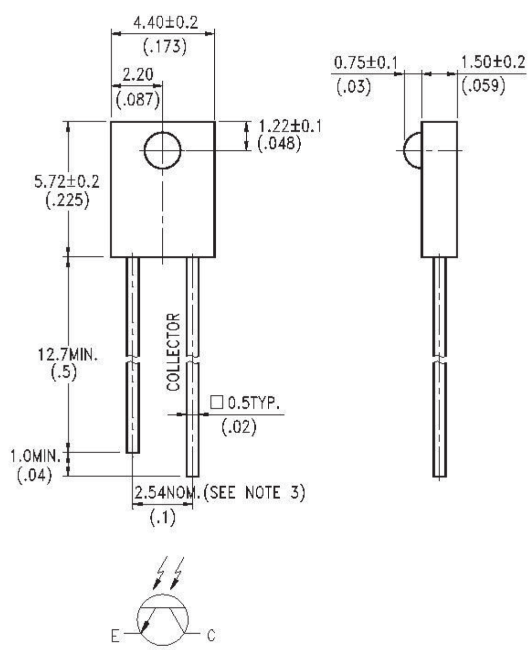
LITEON **LITE-ON ELECTRONICS, INC.**

Property of Lite-On Only

FEATURES

* WIDE RANGE OF COLLECTOR CURRENT
* LENSED FOR HIGH SENSITIVITY
* LOW COST PLASTIC SIDE LOOKING PACKAGE
* CLEAR TRANSPARENT COLOR PACKAGE

PACKAGE DIMENSIONS



NOTES:
1. All dimensions are in millimeters (inches).
2. Tolerance is ± 0.25mm(.010") unless otherwise noted.
3. Lead spacing is measured where the leads emerge from the package.
4. Specifications are subject to change without notice.

Part No. : LTR-301 DATA SHEET	Page : 1 of 3

BNS-OD-C131/A4

LITE-ON ELECTRONICS, INC.

Property of Lite-On Only

ABSOLUTE MAXIMUM RATINGS AT TA=25℃

PARAMETER	MAXIMUM RATING	UNIT
Power Dissipation	100	mW
Collector-Emitter Voltage	30	V
Emitter-Collector Voltage	5	V
Operating Temperature Range	-40℃ to + 85℃	
Storage Temperature Range	-55℃ to + 100℃	
Lead Soldering Temperature [1.6mm(.063") From Body]	260℃ for 5 Seconds	

ELECTRICAL OPTICAL CHARACTERISTICS AT TA=25℃

PARAMETER	SYMBOL	MIN.	TYP.	MAX.	UNIT	TEST CONDITION	BIN NO.
Collector-Emitter Breakdown Voltage	$V_{(BR)CEO}$	30			V	I_C = 1mA Ee = 0mW/㎠	
Emitter-Collector Breakdown Voltage	$V_{(BR)ECO}$	5			V	I_E = 100 μA Ee = 0mW/㎠	
Collector Emitter Saturation Voltage	$V_{CE(SAT)}$			0.4	V	I_C = 0.1mA Ee = 1mW/㎠	
Rise Time	Tr		10		μs	V_{CC} = 5V I_C = 1mA R_L = 1KΩ	
Fall Time	Tf		15		μs		
Collector Dark Current	I_{CEO}			100	nA	V_{CE} = 10V Ee = 0mW/㎠	
On State Collector Current	$I_{C(ON)}$	0.20		0.60	mA	V_{CE} = 5V Ee = 1mW/㎠ λ =940nm	BIN A
		0.40		1.08			BIN B
		0.72		1.56			BIN C
		1.04		1.80			BIN D
		1.20		2.40			BIN E
		1.60					BIN F

Part No. : LTR-301 DATA SHEET Page : 2 of 3

BNS-OD-C131/A4

SEN-00241 IR LED

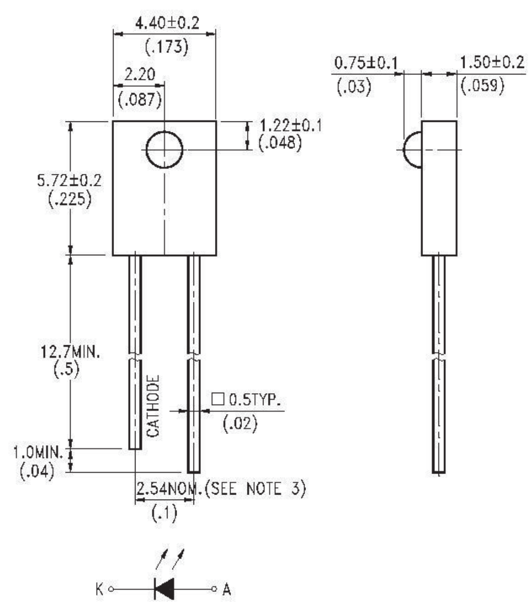
LITEON **LITE-ON ELECTRONICS, INC.**

Property of Lite-On Only

FEATURES

* SELECTED TO SPECIFIC ON-LINE INTENSITY AND RADIANT INTENSITY RANGES
* LOW COST MINIATURE PLASTIC SIDE LOOKING PACKAGE
* MECHANICALLY AND SPECTRALLY MATCHED TO THE LTR-301 SERIES OF PHOTOTRANSISTOR

PACKAGE DIMENSIONS



NOTES:
1. All dimensions are in millimeters (inches).
2. Tolerance is ± 0.25mm(.010") unless otherwise noted.
3. Lead spacing is measured where the leads emerge from the package.
4. Specifications are subject to change without notice.

Part No. : LTE-302 DATA SHEET	Page : 1 of 3

BNS-OD-C131/A4

LITEON L I T E - O N E L E C T R O N I C S , I N C .

Property of Lite-On Only

ABSOLUTE MAXIMUM RATINGS AT TA=25℃

PARAMETER	MAXIMUM RATING	UNIT
Power Dissipation	75	mW
Peak Forward Current (300pps, 10 μs pulse)	1	A
Continuous Forward Current	50	mA
Reverse Voltage	5	V
Operating Temperature Range	-40℃ to + 85℃	
Storage Temperature Range	-55℃ to + 100℃	
Lead Soldering Temperature [1.6mm(.063") From Body]	260℃ for 5 Seconds	

ELECTRICAL OPTICAL CHARACTERISTICS AT TA=25℃

PARAMETER	SYMBOL	MIN.	TYP.	MAX.	UNIT	TEST CONDITION	BIN NO.
Aperture Radiant Incidence	Ee	0.088		0.168	mW/cm^2	I_F = 20mA	BIN B
		0.112		0.204			BIN C
		0.136		0.240			BIN D
		0.160		0.288			BIN E
		0.192					BIN F
Radiant Intensity	I_E	0.662		1.263	mW/sr	I_F = 20mA	BIN B
		0.842		1.534			BIN C
		1.023		1.805			BIN D
		1.203		2.165			BIN E
		1.444					BIN F
Peak Emission Wavelength	λ_{Peak}		940		nm	I_F = 20mA	
Spectral Line Half-Width	$\Delta\lambda$		50		nm	I_F = 20mA	
Forward Voltage	V_F		1.2	1.6	V	I_F = 20mA	
Reverse Current	I_R			100	μA	V_R = 5V	
Viewing Angle (See FIG.6)	$2\theta_{1/2}$		40		deg.		

Part No. : LTE-302 DATA SHEET	Page : 2 of 3

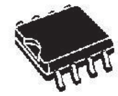
BNS-OD-C131/A4

LE33 3V voltage regulator

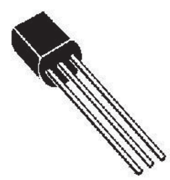
LE00AB/C SERIES

VERY LOW DROP VOLTAGE REGULATORS WITH INHIBIT

- VERY LOW DROPOUT VOLTAGE (0.2V TYP.)
- VERY LOW QUIESCENT CURRENT (TYP. 50µA IN OFF MODE, 0.5mA IN ON MODE, NO LOAD)
- OUTPUT CURRENT UP TO 100 mA
- OUTPUT VOLTAGES OF 1.25; 1.5; 2.5; 2.7; 3; 3.3; 3.5; 4; 4.5; 4.7; 5; 5.2; 5.5; 6; 8V
- INTERNAL CURRENT AND THERMAL LIMIT
- ONLY 2.2µF FOR STABILITY
- AVAILABLE IN ± 1% (A) OR ± 2% (C) SELECTION AT 25 °C
- SUPPLY VOLTAGE REJECTION: 80 db (TYP.)
- TEMPERATURE RANGE: -40 TO 125 °C



SO-8

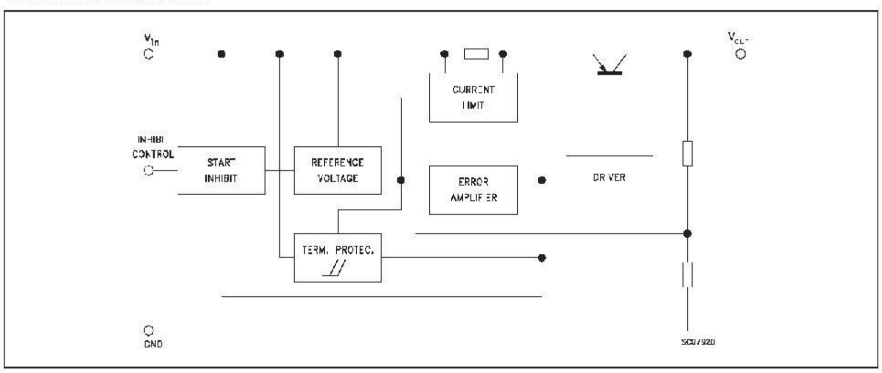


TO-92

DESCRIPTION

The LE00 regulator series are very Low Drop regulators available in SO-8 and TO-92 packages and in a wide range of output voltages.
The very Low Drop voltage (0.2V) and the very low quiescent current make them particularly suitable for Low Noise Low Power applications and specially in battery powered systems.
They are pin to pin compatible with the older L78L00 series. Furthermore in the 8 pin configuration (SO-8) they employ a Shutdown Logic Control (pin 5, TTL compatible). This means that when the device is used as a local regulator, it's possible to put in stand by a part of the board even more decreasing the total power consumption. In the three terminal configuration (TO-92) the device is even in ON STATE, mantaining the same electrical performances. It needs only 2.2µF capacitor for stability allowing room and cost saving effect.

SCHEMATIC DIAGRAM



September 1998 1/25

LM2940 voltage regulator

National Semiconductor

January 2007

LM2940/LM2940C 1A Low Dropout Regulator

LM2940/LM2940C 1A Low Dropout Regulator

General Description

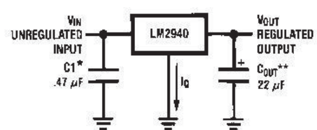
The LM2940/LM2940C positive voltage regulator features the ability to source 1A of output current with a dropout voltage of typically 0.5V and a maximum of 1V over the entire temperature range. Furthermore, a quiescent current reduction circuit has been included which reduces the ground current when the differential between the input voltage and the output voltage exceeds approximately 3V. The quiescent current with 1A of output current and an input-output differential of 5V is therefore only 30 mA. Higher quiescent currents only exist when the regulator is in the dropout mode ($V_{IN} - V_{OUT} \leq 3V$).

Designed also for vehicular applications, the LM2940/LM2940C and all regulated circuitry are protected from reverse battery installations or 2-battery jumps. During line transients, such as load dump when the input voltage can momentarily exceed the specified maximum operating voltage, the regulator will automatically shut down to protect both the internal circuits and the load. The LM2940/LM2940C cannot be harmed by temporary mirror-image insertion. Familiar regulator features such as short circuit and thermal overload protection are also provided.

Features

- Dropout voltage typically 0.5V @I_O = 1A
- Output current in excess of 1A
- Output voltage trimmed before assembly
- Reverse battery protection
- Internal short circuit current limit
- Mirror image insertion protection
- P+ Product Enhancement tested

Typical Application



*Required if regulator is located far from power supply filter.

**C_{OUT} must be at least 22 µF to maintain stability. May be increased without bound to maintain regulation during transients. Locate as close as possible to the regulator. This capacitor must be rated over the same operating temperature range as the regulator and the ESR is critical; see curve.

Ordering Information

Temp Range	Output Voltage						Package
	5.0	8.0	9.0	10	12	15	
0°C ≤ T_J ≤ 125°C	LM2940CT-5.0	–	LM2940CT-9.0	–	LM2940CT-12	LM2940CT-15	TO-220
	LM2940CS-5.0	–	LM2940CS-9.0	–	LM2940CS-12	LM2940CS-15	TO-263
	LM2940CSX -5.0	–	LM2940CSX -9.0	–	LM2940CSX -12	LM2940CSX -15	
−40°C ≤ T_J ≤ 125°C	LM2940LD-5.0	LM2940LD-8.0	LM2940LD-9.0	LM2940LD-10	LM2940LD-12	LM2940LD-15	LLP 1k Units Tape and Reel
	LM2940LDX -5.0	LM2940LDX -8.0	LM2940LDX -9.0	LM2940LDX -10	LM2940LDX -12	LM2940LDX -15	LLP 4.5k Units Tape and Reel
−40°C ≤ T_J ≤ 125°C	LM2940T-5.0	LM2940T-8.0	LM2940T-9.0	LM2940T-10	LM2940T-12	–	TO-220
	LM2940S-5.0	LM2940S-8.0	LM2940S-9.0	LM2940S-10	LM2940S-12	–	TO-263
	LM2940SX-5.0	LM2940SX-8.0	LM2940SX-9.0	LM2940SX-10	LM2940SX-12	–	

Micro-SD card

KINGMAX

Micro SD

SPI mode pin definition

Pin	Name	Type[1]	Description
1	RSV	-	
2	CS	I	Chip Select(Neg. True)
3	DI	I	Data In
4	V_{CC}	S	Supply Voltage
5	CLK	I	Clock
6	V_{SS}	S	Ground
7	DO	O/pp	Data Out
8	RSV	-	

1 S: Power Supply, I: Input O: Output I/O: Bi-directionally PP: I/O using push-pull drivers

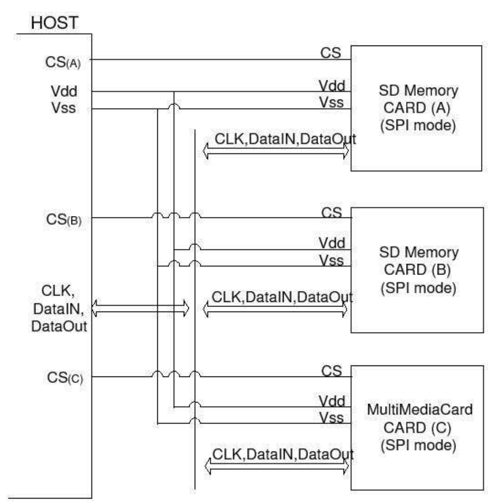
Note: These signals should be pulled up by host side with 10~100K ohm resistance in the SPI mode.

SPI Bus Concept

The SPI bus allows one bit data line by 2-chanel(Data In and Out). The SPI compatible mode allows the MMC Host systems to use MicroSD card with little change. SPI mode is byte transfers.

All the data token are multiples of the bytes(8 bit) and always byte aligned to the CS signal. The advantage of the SPI mode is reducing the host design in effort. Especially, MMC host can be modified with little change.

The disadvantage of the SPI mode is the loss of performance versus SD card mode.



SPI mode bus topology

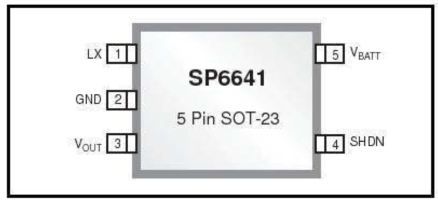
7

SP6641 DC-DC booster

SP6641A/6641B

500mA Alkaline DC/DC Boost Regulator in SOT-23

- Ultra Low Quiescent Current: 10μA
- Wide Input Voltage Range: 0.9V to 4.5V
- 90mA I_{OUT} at 1.3V Input (SP6641A-3.3V)
- 500mA I_{OUT} at 2.6V Input (SP6641B-3.3V)
- 100mA I_{OUT} at 2.0V Input (SP6641A-5.0V)
- 500mA I_{OUT} at 3.3V Input (SP6641B-5.0V)
- Fixed 3.3V or 5.0V Output Voltage
- Up to 87% Efficiency
- 0.3Ω NFET R_{DS}on
- Startup Voltage Guaranteed at 0.9V
- 0.33A Inductor Current Limit (SP6641A)
- 1A Inductor Current Limit (SP6641B)
- Logic Shutdown Control
- SOT-23-5 Package



APPLICATIONS

- PDA's
- DSC's
- CD/MP3 Players
- Pagers
- Digital Cameras
- Portable Handheld Medical Devices

Now Available in Lead Free Packaging

DESCRIPTION

The SP6641 is an ultra-low quiescent current, high efficiency, DC-DC boost converter designed for single and dual cell alkaline, or Li-ion battery applications found in PDA's, MP3 players, and other handheld portable devices. The SP6641 features a 10μA quiescent current, a 0.3Ω N-channel charging switch, 0.9V input startup, and a 0.33A or 1.0A inductor current limiting feature. The SP6641 is offered in a 5 pin SOT-23 package and provides an extremely small power supply footprint optimized for portable applications. The SP6641 is preset to 3.3V and can be controlled by a 1nA active LOW shutdown pin.

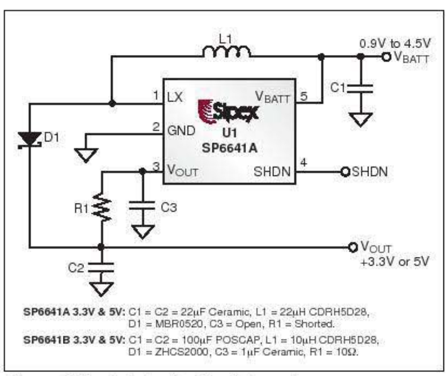


Figure 1. Typical Application Schematic

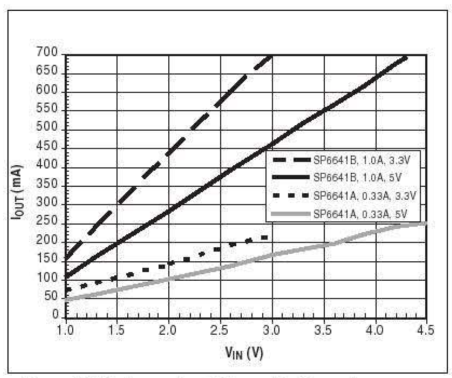


Figure 2. Maximum Load Current in Operation

Rev. 5/26/05, **Patent Pending* SP6641A/6641B 500mA Alkaline DC/DC Boost Regulator in SOT-23

1

MCP73831/2 charger management

MICROCHIP

MCP73831/2

Miniature Single-Cell, Fully Integrated Li-Ion, Li-Polymer Charge Management Controllers

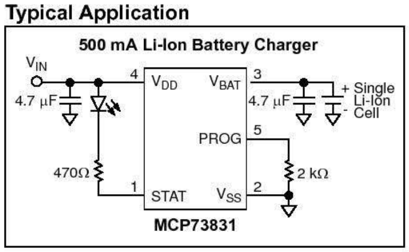
Features

- Linear Charge Management Controller:
  - Integrated Pass Transistor
  - Integrated Current Sense
  - Reverse Discharge Protection
- High Accuracy Preset Voltage Regulation: ± 0.75%
- Four Voltage Regulation Options:
  - 4.20V, 4.35V, 4.40V, 4.50V
- Programmable Charge Current: 15 mA to 500 mA
- Selectable Preconditioning:
  - 10%, 20%, 40%, or Disable
- Selectable End-of-Charge Control:
  - 5%, 7.5%, 10%, or 20%
- Charge Status Output
  - Tri-State Output - MCP73831
  - Open-Drain Output - MCP73832
- Automatic Power-Down
- Thermal Regulation
- Temperature Range: -40°C to +85°C
- Packaging:
  - 8-Lead, 2 mm x 3 mm DFN
  - 5-Lead, SOT-23

Applications

- Lithium-Ion/Lithium-Polymer Battery Chargers
- Personal Data Assistants
- Cellular Telephones
- Digital Cameras
- MP3 Players
- Bluetooth Headsets
- USB Chargers

Typical Application



Description:

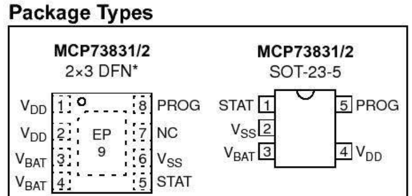
The MCP73831/2 devices are highly advanced linear charge management controllers for use in space-limited, cost-sensitive applications. The MCP73831/2 are available in an 8-Lead, 2 mm x 3 mm DFN package or a 5-Lead, SOT-23 package. Along with their small physical size, the low number of external components required make the MCP73831/2 ideally suited for portable applications. For applications charging from a USB port, the MCP73831/2 adhere to all the specifications governing the USB power bus.

The MCP73831/2 employ a constant-current/constant-voltage charge algorithm with selectable preconditioning and charge termination. The constant voltage regulation is fixed with four available options: 4.20V, 4.35V, 4.40V or 4.50V, to accommodate new, emerging battery charging requirements. The constant current value is set with one external resistor. The MCP73831/2 devices limit the charge current based on die temperature during high power or high ambient conditions. This thermal regulation optimizes the charge cycle time while maintaining device reliability.

Several options are available for the preconditioning threshold, preconditioning current value, charge termination value and automatic recharge threshold. The preconditioning value and charge termination value are set as a ratio, or percentage, of the programmed constant current value. Preconditioning can be disabled. Refer to **Section 1.0 "Electrical Characteristics"** for available options and the **"Product Identification System"** for standard options.

The MCP73831/2 devices are fully specified over the ambient temperature range of -40°C to +85°C.

Package Types



* Includes Exposed Thermal Pad (EP); see Table 3-1.

 DS21984E-page 1

6.0 APPLICATIONS

The MCP73831/2 are designed to operate in conjunction with a host microcontroller or in a stand-alone application. The MCP73831/2 provide the preferred charge algorithm for Lithium-Ion and Lithium-Polymer cells constant current followed by constant voltage. Figure 6-1 depicts a typical stand-alone application circuit, while Figures 6-2 and 6-3 depict the accompanying charge profile.

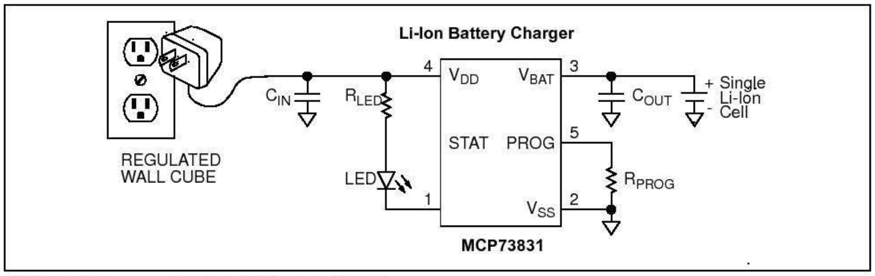


FIGURE 6-1: Typical Application Circuit.

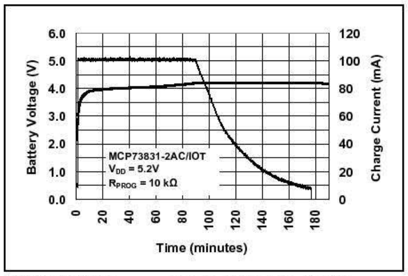


FIGURE 6-2: Typical Charge Profile (180 mAh Battery).

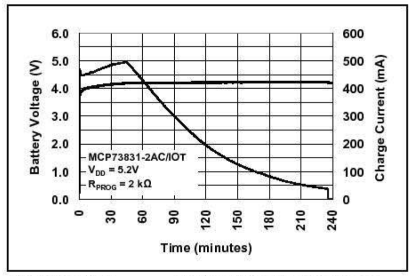


FIGURE 6-3: Typical Charge Profile in Thermal Regulation (1000 mAh Battery).

6.1 Application Circuit Design

Due to the low efficiency of linear charging, the most important factors are thermal design and cost, which are a direct function of the input voltage, output current and thermal impedance between the battery charger and the ambient cooling air. The worst-case situation is when the device has transitioned from the Preconditioning mode to the Constant-Current mode. In this situation, the battery charger has to dissipate the maximum power. A trade-off must be made between the charge current, cost and thermal requirements of the charger.

6.1.1 COMPONENT SELECTION

Selection of the external components in Figure 6-1 is crucial to the integrity and reliability of the charging system. The following discussion is intended as a guide for the component selection process.

6.1.1.1 Current Programming Resistor (R_{PROG})

The preferred fast charge current for Lithium-Ion cells is at the 1C rate, with an absolute maximum current at the 2C rate. For example, a 500 mAh battery pack has a preferred fast charge current of 500 mA. Charging at this rate provides the shortest charge cycle times without degradation to the battery pack performance or life.

TPS61XX booster converter

TEXAS INSTRUMENTS
www.ti.com

TPS61200
TPS61201
TPS61202

SLVS577B–MARCH 2007–REVISED FEBRUARY 2008

LOW INPUT VOLTAGE SYNCHRONOUS BOOST CONVERTER WITH 1.3-A SWITCHES

FEATURES

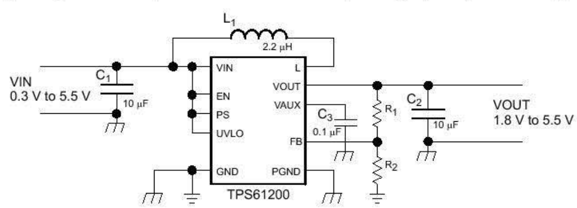
- **More than 90% Efficiency at**
  - **300 mA Output Current at 3.3 V (VIN ≥ 2.4 V)**
  - **600 mA Output Current at 5 V (VIN ≥ 3 V)**
- **Automatic Transition between Boost Mode and Down Conversion Mode**
- **Device Quiescent Current less than 55 µA**
- **Startup into Full Load at 0.5 V Input Voltage**
- **Operating Input Voltage Range from 0.3 V to 5.5 V**
- **Programmable Undervoltage Lockout Threshold**
- **Output Short Circuit Protection Under all Operating Conditions**
- **Fixed and Adjustable Output Voltage Options from 1.8 V to 5.5 V**
- **Power Save Mode for Improved Efficiency at Low Output Power**
- **Forced fixed Frequency Operation possible**
- **Load Disconnect During Shutdown**
- **Overtemperature Protection**
- **Small 3 mm x 3 mm QFN-10 Package**

APPLICATIONS

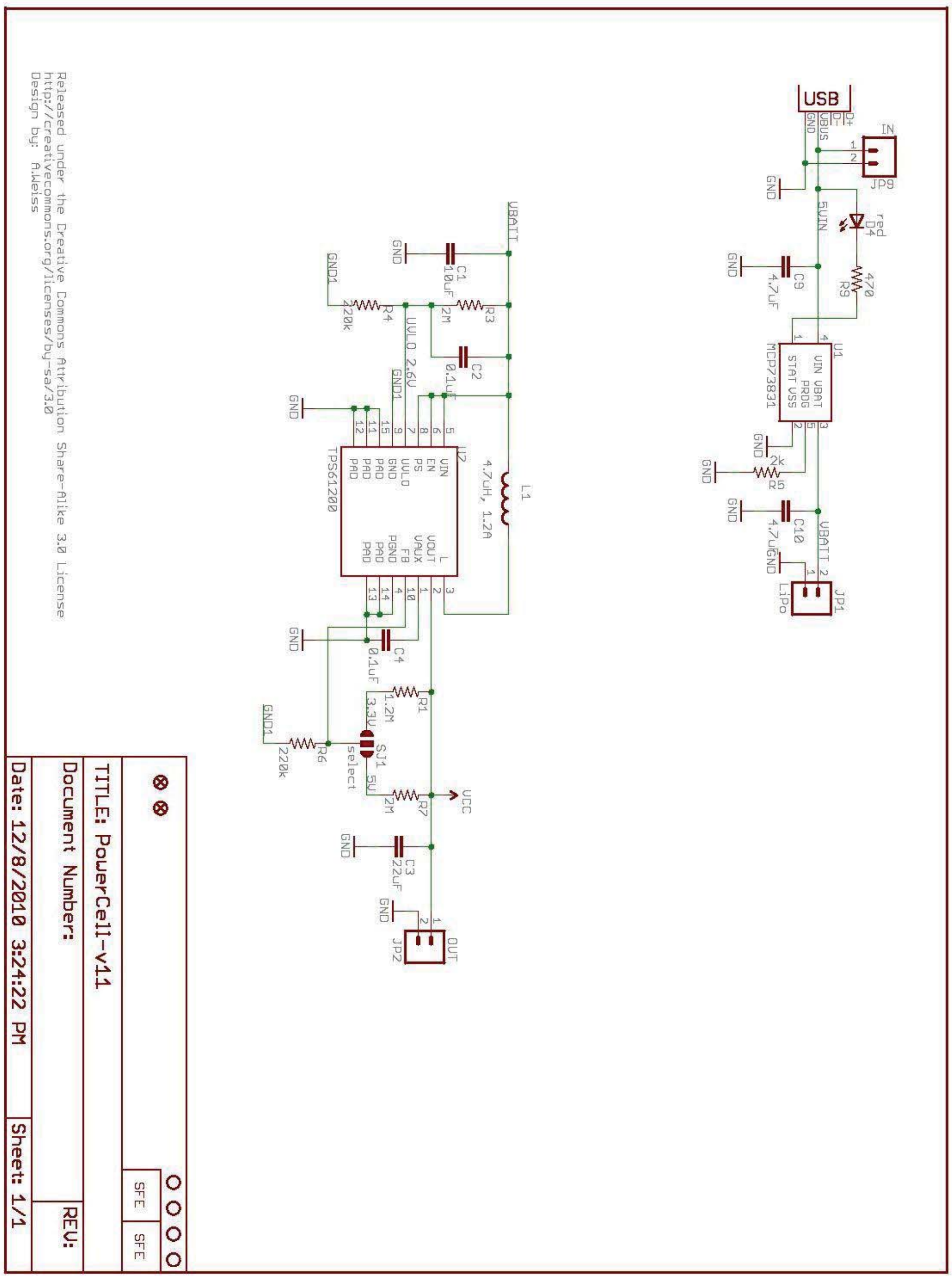
- **All Single-Cell, Two-Cell and Three-Cell Alkaline, NiCd or NiMH or Single-Cell Li Battery Powered Products**
- **Fuel Cell And Solar Cell Powered Products**
- **Portable Audio Players**
- **PDAs**
- **Cellular Phones**
- **Personal Medical Products**
- **White LED's**

DESCRIPTION

The TPS6120x devices provide a power supply solution for products powered by either a single-cell, two-cell, or three-cell alkaline, NiCd or NiMH, or one-cell Li-Ion or Li-polymer battery. It is also used in fuel cell or solar cell powered devices where the capability of handling low input voltages is essential. Possible output currents are depending on the input to output voltage ratio. The devices provides output currents up to 600 mA at a 5-V output while using a single-cell Li-Ion or Li-Polymer battery, and discharge it down to 2.5 V. The boost converter is based on a fixed frequency, pulse-width-modulation (PWM) controller using synchronous rectification to obtain maximum efficiency. At low load currents, the converter enters the Power Save mode to maintain a high efficiency over a wide load current range. The Power Save mode can be disabled, forcing the converter to operate at a fixed switching frequency. The maximum average input current is limited to a value of 1500 mA. The output voltage can be programmed by an external resistor divider, or is fixed internally on the chip. The converter can be disabled to minimize battery drain. During shutdown, the load is completely disconnected from the battery. The device is packaged in a 10-pin QFN PowerPAD™ package (DRC) measuring 3 mm x 3 mm.



Booster/charger schematic



LM358 dual OP-AMP

National Semiconductor

October 2005

LM158/LM258/LM358/LM2904 Low Power Dual Operational Amplifiers

General Description

The LM158 series consists of two independent, high gain, internally frequency compensated operational amplifiers which were designed specifically to operate from a single power supply over a wide range of voltages. Operation from split power supplies is also possible and the low power supply current drain is independent of the magnitude of the power supply voltage.

Application areas include transducer amplifiers, dc gain blocks and all the conventional op amp circuits which now can be more easily implemented in single power supply systems. For example, the LM158 series can be directly operated off of the standard +5V power supply voltage which is used in digital systems and will easily provide the required interface electronics without requiring the additional ±15V power supplies.

The LM358 and LM2904 are available in a chip sized package (8-Bump micro SMD) using National's micro SMD package technology.

Unique Characteristics

- In the linear mode the input common-mode voltage range includes ground and the output voltage can also swing to ground, even though operated from only a single power supply voltage.
- The unity gain cross frequency is temperature compensated.
- The input bias current is also temperature compensated.

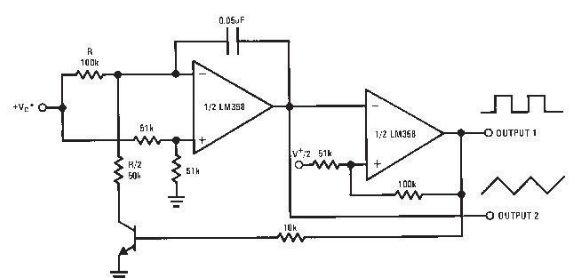
Advantages

- Two internally compensated op amps
- Eliminates need for dual supplies
- Allows direct sensing near GND and V_{OUT} also goes to GND
- Compatible with all forms of logic
- Power drain suitable for battery operation

Features

- Available in 8-Bump micro SMD chip sized package, (See AN-1112)
- Internally frequency compensated for unity gain
- Large dc voltage gain: 100 dB
- Wide bandwidth (unity gain): 1 MHz (temperature compensated)
- Wide power supply range:
  — Single supply: 3V to 32V
  — or dual supplies: ±1.5V to ±16V
- Very low supply current drain (500 μA) — essentially independent of supply voltage
- Low input offset voltage: 2 mV
- Input common-mode voltage range includes ground
- Differential input voltage range equal to the power supply voltage
- Large output voltage swing

Voltage Controlled Oscillator (VCO)



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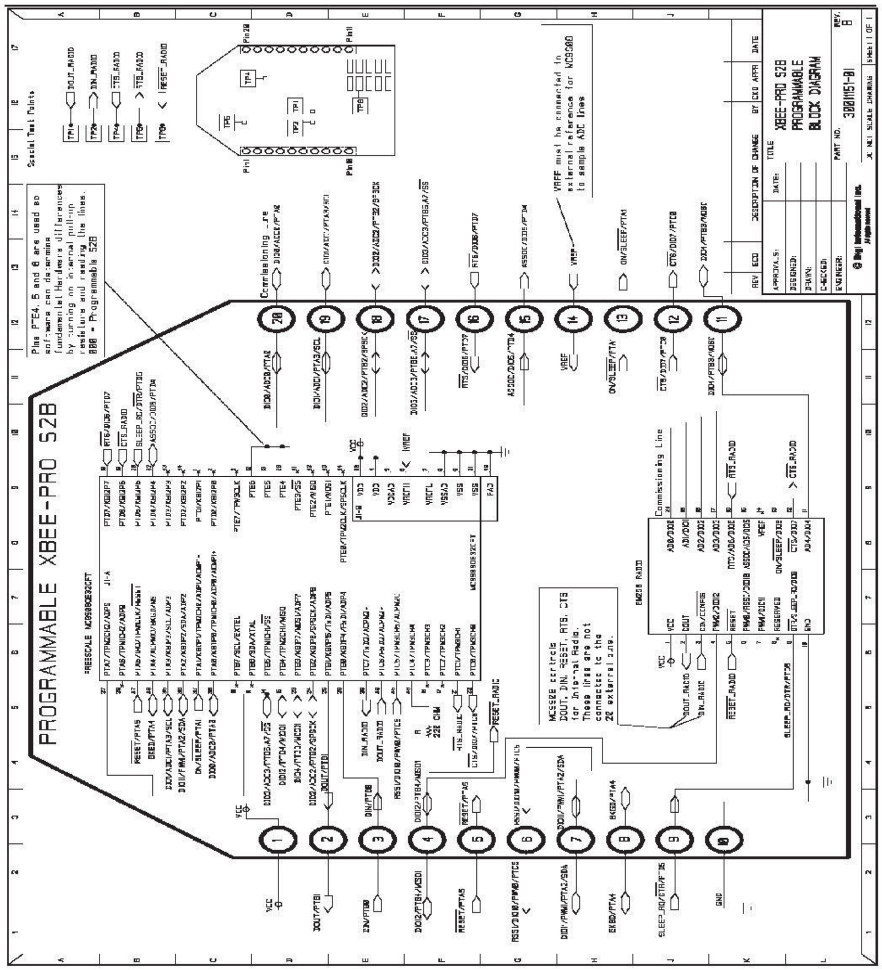
LM158/LM258/LM358/LM2904 Low Power Dual Operational Amplifiers

XBee module specifications

XBee®/XBee-PRO® ZB RF Modules



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XBee®/XBee-PRO® ZB RF Modules

Specifications

Specifications of the XBee®/XBee-PRO® ZB RF Module

Specification	XBee	XBee-PRO (S2)	XBee-PRO (S2B)
Performance			
Indoor/Urban Range	up to 133 ft. (40 m)	Up to 300 ft. (90 m), up to 200 ft (60 m) international variant	Up to 300 ft. (90 m), up to 200 ft (60 m) international variant
Outdoor RF line-of-sight Range	up to 400 ft. (120 m)	Up to 2 miles (3200 m), up to 5000 ft (1500 m) international variant	Up to 2 miles (3200 m), up to 5000 ft (1500 m) international variant
Transmit Power Output	2mW (+3dBm), boost mode enabled 1.25mW (+1dBm), boost mode disabled	50mW (+17 dBm) 10mW (+10 dBm) for International variant	63mW (+18 dBm) 10mW (+10 dBm) for International variant
RF Data Rate	250,000 bps	250,000 bps	250,000 bps
Data Throughput	up to 35000 bps (see chapter 4)	up to 35000 bps (see chapter 4)	up to 35000 bps (see chapter 4)
Serial Interface Data Rate (software selectable)	1200 bps - 1 Mbps (non-standard baud rates also supported)	1200 bps - 1 Mbps (non-standard baud rates also supported)	1200 bps - 1 Mbps (non-standard baud rates also supported)
Receiver Sensitivity	-96 dBm, boost mode enabled -95 dBm, boost mode disabled	-102 dBm	-102 dBm
Power Requirements			
Supply Voltage	2.1 - 3.6 V	3.0 - 3.4 V	2.7 - 3.6 V
Operating Current (Transmit, max output power)	40mA (@ 3.3 V, boost mode enabled) 35mA (@ 3.3 V, boost mode disabled)	295mA (@3.3 V) 170mA (@3.3 V) international variant	205mA, up to 220 mA with programmable variant (@3.3 V) 117mA, up to 132 mA with programmable variant (@3.3 V), International variant
Operating Current (Receive))	40mA (@ 3.3 V, boost mode enabled) 38mA (@ 3.3 V, boost mode disabled)	45 mA (@3.3 V)	47 mA, up to 62 mA with programmable variant (@3.3 V)
Idle Current (Receiver off)	15mA	15mA	15mA
Power-down Current	< 1 uA @ 25°C	3.5 μA typical @ 25°C	3.5 μA typical @ 25°C
General			
Operating Frequency Band	ISM 2.4 GHz	ISM 2.4 GHz	ISM 2.4 GHz
Dimensions	0.960" x 1.087" (2.438cm x 2.761cm)	0.960 x 1.297 (2.438cm x 3.294cm)	0.960 x 1.297 (2.438cm x 3.294cm)
Operating Temperature	-40 to 85º C (industrial)	-40 to 85º C (industrial)	-40 to 85º C (industrial)
Antenna Options	Integrated Whip, Chip, RPSMA, or U.FL Connector	Integrated Whip, Chip, RPSMA, or U.FL Connector	Integrated Whip,PCB Embedded Trace, RPSMA, or U.FL Connector
Networking & Security			
Supported Network Topologies	Point-to-point, Point-to-multipoint, Peer-to-peer, and Mesh	Point-to-point, Point-to-multipoint, Peer-to-peer, and Mesh	Point-to-point, Point-to-multipoint, Peer-to-peer, and Mesh
Number of Channels	16 Direct Sequence Channels	14 Direct Sequence Channels	15 Direct Sequence Channels
Channels	11 to 26	11 to 24	11 to 25
Addressing Options	PAN ID and Addresses, Cluster IDs and Endpoints (optional)	PAN ID and Addresses, Cluster IDs and Endpoints (optional)	PAN ID and Addresses, Cluster IDs and Endpoints (optional)
Agency Approvals			
United States (FCC Part 15.247)	FCC ID: OUR-XBEE2	FCC ID: MCQ-XBEEPRO2	FCC ID: MCQ-PROS2B
Industry Canada (IC)	IC: 4214A-XBEE2	IC: 1846A-XBEEPRO2	IC: 1846A-PROS2B
Europe (CE)	ETSI	ETSI (International variant)	ETSI (10 mW max)

 9

LITEON LCD display

BATRON

VL-FS-BTHQ 21603VSS-05 REV. B
(BTHQ 21603V-SMN-LEDwhite-conn. (1 die))

JUNE/2003

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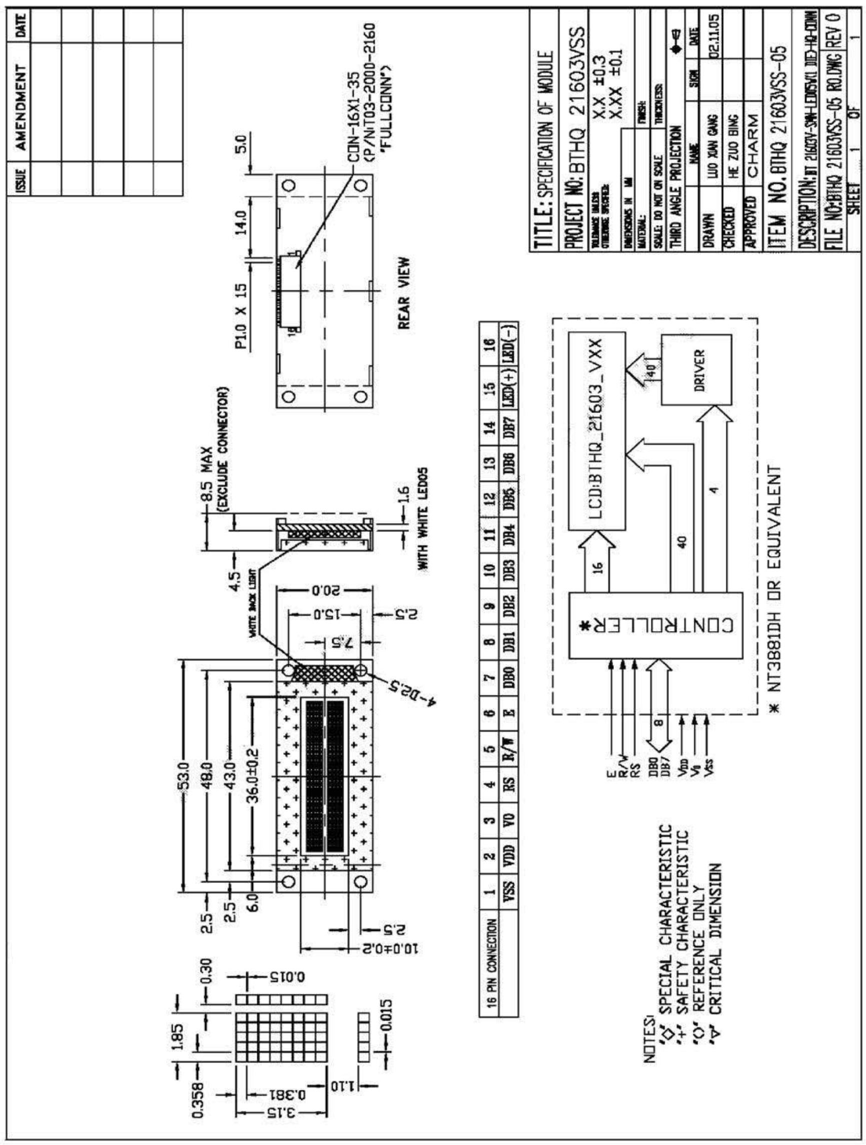

Figure 1: Module Specification

DATA MODUL AG Landsberger Str. 322 80687 München Tel.: 089/ 56017-0 Fax 089/ 56017-119 www.data-modul.de

BATRON

VL-FS-BTHQ 21603VSS-05 REV. B
(BTHQ 21603V-SMN-LEDwhite-conn. (1 die))

JUNE/2003

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3. Interface signals

Table 2

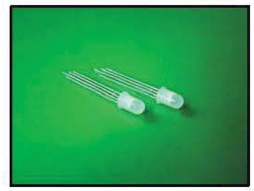
Pin No.	Symbol	Description
1	VSS	Ground (0V).
2	VDD	Power supply for logic (+5V)
3	V0	Power supply for LCD driver
4	RS	Register Select Input: “High” for Data register (for read and write) “Low” for Instruction register (for write), Busy flag, address counter (for read)
5	R/W	Read/Write signal: “High” for Read mode. “Low” for Write mode.
6	E	Enable. Start signal for data read /write.
7	DB0	Data input/output (LSB)
8	DB1	Data input/output
9	DB2	Data input/output
10	DB3	Data input/output
11	DB4	Data input/output
12	DB5	Data input/output
13	DB6	Data input/output
14	DB7	Data input/output (MSB)
15	LED(+)	Anode of LED backlight
16	LED(-)	Cathode of LED backlight

DATA MODUL AG Landsberger Str. 322 80687 München Tel.: 089/ 56017-0 Fax 089/ 56017-119 www.data-modul.de

TRI-colour LED

深圳市昱申科技有限公司
CHINA YOUNG SUN LED TECHNOLOGY CO., LTD.
TEL: (86) 755-28079401 28079402 28079403 28079404 28079405
FAX: (86) 755-28079407 E-mail: info@100LED.com Web: www.100LED.com

Model No.: YSL-R596CR3G4B5W-F12
RED/GREEN/BLUE Triple Color LED white diffused lens



Applications:

- Moving Message Display
- Full Color Display
- Banking Board
- Score Boards
- Digital Display

LED Chip Absolute Maximum Ratings: (Ta=25℃)

Pararmeter	Symbol	Red	Green	Blue	Unit
Forward curret	I_F	20	20	20	mA
Peak forward current (Duty Cycle=1/10, 10KHz)	I_{PF}	30	30	30	mA
Reverse voltage (V_R=5V)	I_R	10	10	10	μA
Operating temp	T_{OPR}	-25 - 85	-25 - 85	-25 - 85	℃
Storage temp	T_{STG}	-30-85	-30-85	-30-85	℃
Peak Emission Wavelenength	λ_{PH}	625	520	467.5	nm

* Soldering Bath: not more than 5 seconds @260℃.The bottom ends of the plastic reflector should be at least 2mm above the solder surface

Soldering Iron: not more than 3 seconds @300℃ under 30W

LED Chip Typical Electircal & Optical Chara Qeristics: (Ta=25℃)

ITEMS	Color	Symbol	Condition	Min.	Typ.	Max.	Unit
Forward Voltage	Red	V_F	I_F=20mA	1.8	2.0	2.2	V
	Green			3.0	3.2	3.4	
	Blue			3.0	3.2	3.4	
Luminous Intensity	Red	I_V	I_F=20mA	---	---	2800	mcd
	Green			---	---	6500	
	Blue			---	---	1200	
Wavelenength	Red	$\Delta\lambda$	I_F=20mA	620	623	625	nm
	Green			520	521	522.5	
	Blue			465	466	467.5	
Light Degradation after 1000 hours	Red	-4.68% ~ -8.27%					
	Green	-11.37% ~ -15.30%					
	Blue	-8.23% ~ -16.81%					

Address: 5/F, Building B, Anzhilong Indl., Qinghua East Road., Longhua Town, Shenzhen CHINA. 518109