

Copyright is owned by the Author of the thesis. Permission is given for a copy to be downloaded by an individual for the purpose of research and private study only. The thesis may not be reproduced elsewhere without the permission of the Author.



**MASSEY UNIVERSITY**  
**ENGINEERING**

**WIRELESS DATA ACQUISITION  
AND MONITORING FOR  
HEALTHCARE SERVICE SYSTEMS**

A thesis in the partial fulfillment of the requirement for the

**Masters of Engineering**  
**(Electronics and Computer Systems)**

**MASSEY UNIVERSITY**

PALMERSTON NORTH  
NEW ZEALAND

**AMIR HOSHANG KIOUMARS**

**2011**

*This thesis is dedicated to my brother*

*Hashem Xioumars*

*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<sup>1</sup>:

- **Wireless Network for Health Monitoring**  
Fifth International Conference on Sensing Technology  
28<sup>th</sup> November – 1<sup>st</sup> 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  
6<sup>th</sup> – 8<sup>th</sup> December 2011  
Wellington, New Zealand  
pp. 361-365, ISBN of 978-1-4577-0328-7
  
- **Wireless Health Data Acquisition**  
14<sup>th</sup> International Conference on E-Health Networking  
10<sup>th</sup> – 13<sup>th</sup> October 2012  
Beijing, China  
(Submitted)

---

<sup>1</sup> *Appendix A: Publications*

## **ACKNOWLEDGMENTS**

First and foremost, I have to thank my brother Hashem Kioumars, for his support throughout my life. Thank you for giving me strength to reach for the stars and chase my dreams.

I would like to express my deepest appreciation to my great supervisor Dr Liqiong Tang for giving me invaluable guidance, inspiring suggestions with so much enthusiasm throughout my research, of which I am forever grateful.

A very special thanks to my fantastic lecturers at Massey University School of Engineering and Advanced Technology; Professor Richard Harris, Professor Bob Hodgson, Professor Serge Demidenko, Associate Professor Stephen Marsland, Associate Professor Jens Dietrich, Associate Professor Wyatt Page, Dr Ramesh Rayudu, Dr Rose Davis, Dr John Heath, Dr Giovanni Moretti, Mr Ken Mercer and others who have taught me how to think widely and act wisely as an engineer.

Deep thanks to my lovely colleague Marie Russell for her wonderful support and academic mentoring during my study and work at Massey University.

A big thanks to my honourable friend Mohsen Houseinpoor and memorable friend Hojat Peyravi who encouraged me in my entire life and supported me all the way through.

To my great friends, Ali and Mandana Nik-Khoo, Graeme and Jeanette Ekins, Phillip Williams; thank you for all your help and encouragement in many moments of my life. Your friendship makes my life a wonderful experience.

Finally, as a proud New Zealander, I would like to give special thanks to my beautiful and forever green country New Zealand, for giving me the opportunity to live, work and study in peace.



## **INTELLECTUAL 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.

# CONTENTS

<b>ABSTRACT</b> .....	<b>V</b>
<b>ACKNOWLEDGMENTS</b> .....	<b>VII</b>
<b>INTELLECTUAL PROPERTY STATEMENT</b> .....	<b>VIII</b>
<b>CONTENTS</b> .....	<b>IX</b>
<b>LIST OF FIGURES</b> .....	<b>XVI</b>
<b>LIST OF TABLES</b> .....	<b>XXI</b>
<b>LIST OF EQUATIONS</b> .....	<b>XXII</b>
<b>CHAPTER 1 - INTRODUCTION</b> .....	<b>1</b>
1.1. The research topic .....	2
1.2. The scope of research .....	2
1.3. Organization of thesis .....	3
<b>CHAPTER 2 – LITERATURE REVIEW</b> .....	<b>5</b>
2.1. Information technology in healthcare .....	5
2.2. Human vital health signs and their measurements .....	8
2.2.1. Body temperature.....	8
2.2.2. Blood pressure .....	9
2.2.3. Pulse .....	10
2.2.4. Respiratory rate.....	11
2.3. Service robot in healthcare .....	12
2.3.1. Demanding on service robot in healthcare .....	12
2.3.2. The challenges for robots.....	13
2.3.3. Benefits of using service robots .....	13
2.4. Service robot decision making .....	15
2.4.1. Intelligent decision-making.....	15
2.4.2. Technology roadmap for service robot .....	16
2.5. Wireless sensor networks .....	17

2.5.1.	Recent technologies.....	17
2.5.2.	Advantage of wireless sensor network for healthcare .....	17
2.5.3.	Requirements for wireless medical sensors .....	18
2.6.	Wireless communication technologies.....	19
2.6.1.	WiFi .....	19
2.6.2.	WiMAX .....	22
2.6.3.	ZigBee .....	23
2.7.	Comparison between ZigBee and Bluetooth .....	25
2.8.	Comparison of WiFi, ZigBee and WiMAX technologies.....	26
2.9.	ZigBee benefits .....	27
2.9.1.	ZigBee data reliability, rate, latency and security.....	27
2.9.2.	ZigBee size, cost and battery life .....	29
2.9.3.	ZigBee transmission range .....	30
2.10.	ZigBee in healthcare .....	31
2.11.	Real-time health monitoring using ZigBee .....	32
<b>CHAPTER 3 – COMMUNICATION .....</b>		<b>33</b>
3.1.	Wireless communication .....	33
3.2.	XBee explorer .....	34
3.3.	X-CTU software.....	35
3.4.	XBee mesh networks .....	37
3.5.	Creating a XBee mesh network .....	38
3.5.1.	Setting up XBee coordinator and router.....	39
3.5.2.	Testing the XBee network.....	40
3.6.	Standalone XBee benefits and limitations .....	42
3.7.	RF modules.....	43
3.7.1.	RF modules characteristics.....	44
3.7.2.	Setting-up the RF modules .....	45
3.7.3.	RF module antenna length.....	47
3.8.	XBee and RF modules comparisons .....	48

<b>CHAPTER 4 – HARDWARE .....</b>	<b>50</b>
4.1. Micro-controller .....	50
4.2. Arduino micro-controller .....	50
4.2.1.  Arduino micro-controller boards .....	51
4.2.2.  Arduino features .....	52
4.2.3.  Arduino XBee Shield .....	54
4.3.  Temperature sensor .....	55
4.3.1.  Body temperature study .....	55
4.3.2.  TMP36 temperature sensor .....	56
4.3.3.  TMP36 and Arduino micro-controller .....	56
4.3.4.  Estimation of mean-body temperature .....	59
4.4.  Heart rate sensor .....	65
4.4.1.  The principle of pulse oximetry .....	65
4.4.2.  The design of the heart rate sensor .....	67
4.4.3.  Operational amplifiers .....	68
4.4.4.  Acquiring the signals .....	69
4.4.5.  The comparator .....	72
4.4.6.  Heart rate sensor testing .....	80
4.5.  Liquid crystal display .....	81
4.6.  Standalone Arduino .....	82
4.6.1.  ATmega328 chip .....	82
4.6.2.  Voltage regulator .....	84
4.7.  Logging data .....	86
4.7.1.  Memory cards .....	86
4.7.2.  File System .....	87
4.7.3.  Transfer mode .....	87
4.7.4.  Micro-SD card and bus modes .....	88
4.7.5.  Adding memory card to the system .....	89
4.8.  Modular design of the prototype and PCB designs .....	90

4.8.1.	PCB top layer .....	91
4.8.2.	PCB bottom layer .....	92
4.9.	Hardware power source .....	93
4.9.1.	Nickel-Cadmium batteries .....	93
4.9.2.	Nickel-Metal-Hydride batteries .....	94
4.9.3.	Lithium-ion batteries .....	94
4.9.4.	PowerGenix NiZn batteries .....	95
4.9.5.	Selected battery .....	95
4.10.	PowerCell charger-booster .....	97
4.11.	Sensor error factors.....	98
4.12.	Sensor cost analysis .....	99
4.13.	Sensor device power consumption .....	100
4.14.	Hardware unit testing .....	101
<b>CHAPTER 5 – SOFTWARE .....</b>		<b>102</b>
5.1.	Electronic health data.....	102
5.2.	Microsoft .Net .....	102
5.3.	C# programming language.....	103
5.4.	Database .....	105
5.4.1.	Oracle MySQL and Microsoft SQL Server .....	105
5.4.2.	MySQL in healthcare .....	106
5.5.	Micro-controller programming .....	108
5.5.1.	Micro-controller software block diagram .....	108
5.5.2.	Micro-controller software functions .....	109
5.5.3.	Heart rate function.....	109
5.5.4.	Temperature function .....	110
5.5.5.	Structured EEPROM access.....	111
5.5.6.	Lightweight strings.....	112
5.5.7.	Data packet .....	112
5.5.8.	Communication commands.....	114

5.6.	Software requirements .....	116
5.7.	Software system conceptual view .....	117
5.8.	Software architecture .....	119
5.9.	Database design .....	122
5.9.1.	MySQL Workbench .....	122
5.9.2.	Creating database dynamically .....	122
5.10.	T-HBR software .....	124
5.10.1.	Register new user .....	125
5.10.2.	Retrieve login information .....	126
5.10.3.	Gmail SMTP server .....	128
5.10.4.	Gmail to SMS .....	129
5.10.5.	Communication settings .....	130
5.10.6.	Registering a new patient.....	134
5.10.7.	Visiting system .....	135
5.10.8.	Charts reports.....	137
5.10.9.	Admin tools.....	140
5.11.	Software code metrics.....	144
5.11.1.	Maintainability index .....	144
5.11.2.	Cyclomatic complexity.....	144
5.11.3.	Depth of inheritance .....	144
5.11.4.	Class coupling .....	145
5.11.5.	Lines of code .....	145
5.11.6.	Software testing.....	145
<b>CHAPTER 6 – DISCUSSIONS AND CONCLUSIONS .....</b>		<b>146</b>
6.1.	Discussion .....	146
6.1.1.	Communication .....	146
6.1.2.	Hardware .....	147
6.1.3.	Software .....	148
6.2.	Contribution of author.....	150

6.3. Results analysis .....	154
6.4. Conclusions.....	158
<b>REFERENCES.....</b>	<b>160</b>
<b>APPENDIX A – PUBLICATIONS .....</b>	<b>164</b>
Wireless Network for Health Monitoring.....	164
ATmega and XBee-Based Wireless Sensing .....	171
Wireless Health Data Acquisition .....	177
<b>APPENDIX B – MICRO-CONTROLLER UNIT TESTS.....</b>	<b>184</b>
Two way communication unit test .....	184
Micro-SD unit test.....	185
<b>APPENDIX C – T-HBR SOFTWARE .....</b>	<b>187</b>
Database entity-relationship diagram .....	187
T-HBR software classes, methods and properties .....	188
T-HBR memory profiling report .....	191
T-HBR sample profiling report.....	192
T-HBR instrumentations profiling report.....	192
T-HBR software system requirement analysis.....	193
Micro-controller hardware requirement analysis.....	193
Software metrics .....	194
<b>APPENDIX D – SENSORS DATA .....</b>	<b>195</b>
<b>APPENDIX E – HARDWARE .....</b>	<b>196</b>
5V and 3.3V voltage regulators schematic .....	196
Heart rate sensor schematic .....	197
Stand-alone Arduino schematic .....	198
RF modules connections to Arduino schematic.....	199
XBee Arduino connections schematic .....	200
Hardware device PCB design .....	201
<b>APPENDIX F – HARDWARE PARTS/COST ANALYSIS .....</b>	<b>202</b>
<b>APPENDIX G – HARDWARE DEVICE ASSEMBLY .....</b>	<b>203</b>

<b>APPENDIX H – HARDWARE TEST RESULTS .....</b>	<b>211</b>
<b>APPENDIX I – DATASHEETS .....</b>	<b>216</b>
ATmel/ATmega chip.....	216
TMP36 temperature sensor .....	217
SEN-00241 IR Photo-transistor .....	218
SEN-00241 IR LED .....	220
LE33 3V voltage regulator.....	222
LM2940 voltage regulator .....	223
Micro-SD card .....	224
SP6641 DC-DC booster.....	225
MCP73831/2 charger management.....	226
TPS61XX booster converter .....	228
Booster/charger schematic .....	229
LM358 dual OP-AMP .....	230
XBee module specifications .....	231
LITEON LCD display.....	233



## LIST OF FIGURES

Fig 1: Hospital and healthcare security and safety as top priorities for 2004 .....	7
Fig 2: Hospital and healthcare clinical applications as most important for 2004–2005 .....	7
Fig 3: Oral test of body temperature .....	8
Fig 4: Blood pressure .....	9
Fig 5: Pulse .....	10
Fig 6: Schematic diagram of multimodal interactive platform of service.....	15
Fig 7: The process of intelligent decision-making.....	16
Fig 8: Service robots technology roadmap .....	16
Fig 9: Types of wireless communication technologies.....	19
Fig 10: WiFi logo .....	19
Fig 11: Time to transfer 30 minutes video.....	21
Fig 12: WiMAX logo .....	22
Fig 13: ZigBee logo.....	23
Fig 14: ZigBee frequency channels .....	27
Fig 15: Frame types .....	28
Fig 16: ZigBee star, mesh and tree networks .....	29
Fig 17: ZigBee sample application.....	31
Fig 18: Conceptual view of a remote monitoring system .....	32
Fig 19: Mini-USB XBee explorer board (left) - USB XBee dongle (right).....	35
Fig 20: Running XCTU and connect to the XBee .....	36
Fig 21: Result of the test/query of a modem .....	36
Fig 22: A full (top) and partial (bottom) mesh networks .....	37
Fig 23: XBee star (left), tree (middle), combination of star and tree networks (right).....	37
Fig 24: Arduino shield XBee-USB jumpers .....	38
Fig 25: Updating the XBee firmware .....	38
Fig 26: Setting up XBee coordinator and router.....	39

Fig 27: Testing the XBee.....	40
Fig 28: Sample Arduino sketch for testing communication .....	41
Fig 29: KLP/KLPA RF modules: receiver (left) and transmitter (right) .....	43
Fig 30: T/R LP modules .....	44
Fig 31: RF transmitter schematic .....	45
Fig 32: RF transmitter and Arduino UNO connections .....	45
Fig 33: RF receiver schematic .....	46
Fig 34: RF receiver and Arduino Eleven connections.....	46
Fig 35: Arduino UNO .....	52
Fig 36: XBee shield and XBee module .....	54
Fig 37: TMP36 temperature sensor .....	56
Fig 38: TMP36 and Arduino connections.....	57
Fig 39: Output voltage vs temperature.....	58
Fig 40: Output current vs temperature .....	58
Fig 41: Omron digital thermometer vs TMP36 temperature sensor readings.....	61
Fig 42: Omron digital thermometer vs modified data using Burton's equation .....	62
Fig 43: Omron digital thermometer, TMP36 and modified data using Burton's equation .....	63
Fig 44: Infrared and red light wavelength.....	65
Fig 45: Transmission (left) and reflectance (right) methods.....	66
Fig 46: LITE-ON electronics IR emitter and detector - simple heart rate diagram.....	67
Fig 47: LM358 - pins layout.....	68
Fig 48: IR LED, phototransistor and high-pass filter .....	69
Fig 49: Voltage amplification .....	70
Fig 50: Low-pass filter .....	71
Fig 51: First stage of LM358 op-amp .....	71
Fig 52: Electrical characteristics chart for LM358 op-amp.....	72
Fig 53: Simulation of signals entering the comparator of op-amp .....	73
Fig 54: Basic comparator operation .....	73
Fig 55: Comparator - input vs output rules.....	74

Fig 56: Comparator and voltage reference .....	74
Fig 57: Comparator and a TRI-colour LED .....	75
Fig 58: Calculating the resistor value for LED.....	76
Fig 59: Effect of input offset voltage on the output voltage.....	77
Fig 60: Ideal (right) and typical (left) comparator hysteresis .....	78
Fig 61: Adding hysteresis to LM358 comparator and the effect on digital outputs .....	79
Fig 62: Heart rate sensor on breadboard.....	80
Fig 63: Analogue (left) and digital (right) outputs .....	80
Fig 64: 16*2 characters LCD display and its connection to Arduino.....	81
Fig 65: Connecting the LCD display to Arduino micro-controller .....	81
Fig 66: ATmega328 pins layout .....	82
Fig 67: Parallel resonant crystal.....	83
Fig 68: ATmega328 connections schematic .....	83
Fig 69: Standalone ATmega328 chip on breadboard .....	84
Fig 70: LM2940CT-5 typical application.....	84
Fig 71: LM2940CT fixed 5V voltage regulator complete schematic .....	85
Fig 72: LM2940 5V voltage regulator 1- input, 2- regulator, 3-fixed 5V output.....	85
Fig 73: SD (top), Mini-SD (middle), Micro-SD (bottom) .....	86
Fig 74: Micro-SD card PCB layout (left) block diagram (right).....	88
Fig 75: Connecting Micro-SD card to ATmega chip .....	89
Fig 76: Breadboard design with standalone Arduino .....	90
Fig 77: PCB top layer .....	91
Fig 78: Assembled top-layer PCB board.....	91
Fig 79: PCB bottom layer .....	92
Fig 80: Assembled bottom-layer PCB board.....	92
Fig 81: PowerCell charger - booster .....	97
Fig 82: Sensor cost analysis .....	99
Fig 83: My-SQL downloads statistics from April 2008 to April 2009 .....	105
Fig 84: Micro-controller software flow diagram .....	108

Fig 85: Micro-controller heart rate function .....	110
Fig 86: Micro-controller temperature function .....	111
Fig 87: Data packet block diagram .....	112
Fig 88: Data packet broadcasting .....	113
Fig 89: Conceptual view of the software system.....	116
Fig 90: Software system architecture.....	117
Fig 91: 2-Tier and 3-Tier architecture .....	119
Fig 92: MVC and MVP patterns .....	120
Fig 93: Creating database using MySQL Workbench (top) and T-HBR software (bottom).....	123
Fig 94: T-HBR software start-up screen .....	124
Fig 95: Registration form.....	125
Fig 96: Retrieve login information form .....	126
Fig 97: Request, send and receive email.....	127
Fig 98: Gmail and Ozeki NG SMS gateway system architecture .....	129
Fig 99: Communication setup .....	130
Fig 100: List of the registered hardware .....	131
Fig 101: Querying the new device .....	131
Fig 102: Selecting a patient.....	132
Fig 103: Uploading information to the remote device .....	132
Fig 104: Sample online programing the remote device .....	133
Fig 105: Register new patient form .....	134
Fig 106: Patient visit form.....	135
Fig 107: Sample patient visit.....	136
Fig 108: Patient history and previous visits.....	137
Fig 109: Temperature and heart rate graphs .....	138
Fig 110: Temperature and heart rate graphs comparison .....	138
Fig 111: Activating show points values on mouse over .....	139
Fig 112: Admin tools .....	140
Fig 113: Admin: login (left) - change username/password (right) .....	140

Fig 114: Admin backup/restore panel ..... 142

Fig 115: Restore warning message ..... 143

Fig 116: initial and modified vs actual temperature readings..... 154

Fig 117: Comparison of the heart rate readings ..... 155

Fig 118: Effect of IR emitter rotation on light absorption by the receiver ..... 157

## LIST OF TABLES

Table 1: ZigBee and Bluetooth comparison.....	25
Table 2: WiFi, ZigBee and WiMAX technologies .....	26
Table 3: KLP/KLPA RF modules characteristics.....	44
Table 4: Antenna length for different operating frequencies .....	47
Table 5: XBee and RF modules comparisons .....	48
Table 6: Arduino UNO summary .....	52
Table 7: Sample temperature readings.....	59
Table 8: Alpha value for Burton's equation by different studies.....	60
Table 9: Omron digital thermometer vs TMP36 sensor readings .....	61
Table 10: Omron digital thermometer vs modified TMP36 sensor readings .....	62
Table 11: Omron digital thermometer vs TMP36 and modified TMP36 sensor readings.....	63
Table 12: T-test - paired two samples for means .....	63
Table 13: Advantages and limitations of NiCd batteries .....	93
Table 14: Advantages and limitations of NiMH batteries .....	94
Table 15: Batteries overview.....	95
Table 16: Data packet description .....	113
Table 17: Micro-controller commands, abbreviations and description .....	115
Table 18: Micro-controller commands details .....	115
Table 19: Gmail SMTP server configurations .....	128
Table 20: Packet success rate: received by device (left) - send to device (right).....	154
Table 21: Difference readings between sensor device and commercial device .....	155

## LIST OF EQUATIONS

Equation 1: Frequency definition .....	47
Equation 2: Time and frequency relationship.....	47
Equation 3: Calculating the wave-length.....	47
Equation 4: Calculating the antenna length .....	47
Equation 5: Convert ADC value to voltage .....	58
Equation 6: Convert voltage to temperature .....	58
Equation 7: Burton's equation .....	60
Equation 8: Mean body temperature with approximate alpha value.....	60
Equation 9: High-pass filter frequency .....	69
Equation 10: Op-amp Gain .....	70
Equation 11: Low-pass filter frequency.....	70
Equation 12: LED resistor value .....	76
Equation 13: Linear function of temperature voltage error .....	77
Equation 14: Op-amp comparator hysteresis .....	79