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Human Emotion Recognition Using Smart Sensors

A Thesis submitted in fulfilment of the
requirements for the degree of

Master of Engineering

in

Electronics and Communication Engineering

By

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NEW ZEALAND

February 2012

Abstract

Emotions play a vital role in people's everyday life. It is a mental state that does not arise through free will and is often accompanied by physiological changes. Therefore monitoring these changes is important as they are perceptions of emotional changes and can help in identifying matters of concern at an early stage before they become serious. Emotion recognition has become an important subject when it comes to human-machine interaction. Various methods have been used in the past to detect and evaluate human emotions. The most commonly used techniques include the use of textual information, facial expressions, speech, body gestures and physiological signals. In this project we have developed an emotion recognition system based on information provided by the physiological signals. These signals are obtained from a skin temperature sensor, a heart rate sensor, and a skin conductance sensor. The amplified and filtered signals from the sensors are input into the microcontroller where all the processing takes place. The microcontroller wirelessly transmits data to a computer where it is stored for data analyses and feature extraction for emotion recognition. The four basic emotions observed in this project are happy (excited), sad, angry and neutral (relaxed). The data has been collected from healthy individuals, including both male and female, with ages ranging from 18 to 72 years. K-means clustering algorithm has been used to cluster data into four groups (emotions). A graphical user interface (GUI) has been designed to communicate with the hardware as well as display real-time emotion(s) for the monitored period. The developed system has shown an overall emotion recognition rate of 86.25%.

Acknowledgements

First of all I would like to thank God for giving me the courage and strength to carry out my research. I am deeply indebted to Professor Subhas Mukhopadhyay for his continuous support, encouragement, valuable advice, technical help and supervision of my project. Without his help I wouldn't have achieved what I have achieved now.

I would like to acknowledge the help of Mr Ken Mercer, Mr Colin Plaw, Bruce Collins and Anthony Wade regarding technical matters and their invaluable advice to improve experimental works at the laboratory. I would also like to thank Clive Bardell for helping me build the heart rate sensor casing and Mike Lusby for IT support and advice. I would like to acknowledge the effort of Michelle Wagner who was responsible for the paper work throughout the course of project.

I would like to thank Mr. Nagender Suryadevara, PhD student, for his help with GUI development. I would also like to thank Mohd Amri, Mohd Syaifudin, and Anuroop Gaddam, PhD students, whom I turned to for quick technical advice. I also want to acknowledge the effort of all the individuals who participated in data collection for emotion evaluation and recognition. Special thanks to family and friends who were there for me and supported me where ever and whenever they could.

Finally I would like to thank my parents for their unconditional love and support. Thank you for all the sacrifices you have made to give me a better chance in life.

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1.0 Introduction

Improving human health has been the subject of many research investigations. Recent research studies have been focused on improving the quality of human life in terms of health by designing and fabricating sensors which are either in direct contact with the human body or indirectly. These sensor based systems would have a positive impact on the annual medical cost and the health management system as it would allow for early detection of physiological and emotional changes. Emotions play critical role in rational and intelligent behaviour. It is a mental state that does not arise through free will and is often accompanied by physiological changes. These changes need to be monitored as they contain information about different types of emotions which will assist in understanding behaviors. The main objectives of this project are to design a real time monitoring system, capable of evaluating four basic emotions i.e. happy, sad, angry and neutral, using low cost and non-invasive physiological sensors. The system should be capable of monitoring data in a comfortable and unobtrusive manner, with the ability of wirelessly communication.

In order to achieve these objectives, a literature review was conducted to analyse the different types of emotion recognition techniques and methods that are available. The emotion recognition systems researched are those that use text, facial expressions, speech, body gestures and movements, and physiological signals. An overview of the steps involved in transmission of physiological signal data from the sensors to the computer for data analysis and emotion recognition is then given. Three physiological parameters are chosen for this project i.e. heart rate, skin temperature, and skin conductance response. The data processing is carried out using a microcontroller and ZigBee wireless technology is used for wireless data transmission. A graphical user interface is developed for real time data monitoring, its analyses and emotion recognition. Parameters for emotion recognition are set based on training data collected from healthy individuals. The system is developed to analyse the test data based on the provided training data to recognize the emotional states. The results obtained are discussed and conclusions drawn. Ideas for further developments of this emotion recognition system are put forth.

2.0 Literature Review

Emotions play a vital role in people's everyday life. It is a mental state that does not arise through free will and is often accompanied by physiological changes [1]. Emotions play a central role in decision making, problem solving, communicating, negotiating, and adapting to unpredictable environments. It consists of external physical expression as well as internal feelings, thoughts and internal processes which the person experiencing the emotion may not be aware of. According to AlMejrad [2] emotions play critical roles in rational and intelligent behaviour. When people are happy, their perception is biased at selecting happy events, likewise for negative emotions. Similarly, while making decisions, users are often influenced by their affective states.

Emotions can be categorised into various types. In 1969, Ekman [3] studied emotions in different cultures using facial expressions. He found six basic emotions i.e. happiness, sadness, fear, surprise, anger, and disgust. These six basic emotions have been widely accepted and used till date. Ekman [4] later expanded his list and included amusement, contempt, contentment, embarrassment, excitement, guilt, pride in achievement, relief, satisfaction, sensory pleasure, and shame. Recently, AlMejrad [2] studied human emotions using brain wave signals and classified human emotions into three types, i.e. motivational, basic and self conscious or social. These types represented different emotions i.e. motivational type consists of thirst, hunger, pain and mood, basic type consists of happy, sad, fear, disgust, anger and surprise while self conscious or social type consists of shame, embarrassment, pride and guilt.

Finding relationship between emotions and actions has been an important topic for philosophers, psychologists, and neurobiologists. Thagard [5, 6] developed a computational model to reconcile both emotion-based and deliberative decision making mechanisms based on his theory of emotional coherence. According to him the main advantage of emotion-based decision-making is speed and efficiency as emotion help to frame the options of action to be evaluated. Those courses of action associated with strong negative emotional feelings are eliminated from

consideration at the outset. He [7] adds that emotions contribute significantly to the processes of action generation as well as action execution and control. According to de Sousa [8], emotions fall somewhere in between clear cases of activity (intentional actions), and clear cases of passivity (involuntary physiological processes). Emotions might not be the same as actions but that does not imply that emotions can be separated from our understanding of the nature of action. Similarly Damasio [9, 10] called emotions an integral part of the process of reasoning and decision making. He found that some patients with neurological damage in specific sites of their brains who lost their ability to process emotion normally also lost their ability to make rational decisions in everyday life, but their abstract reasoning and logic skills remained intact. Prinz [11] in his study on basic emotions compared sneezing and emotions. According to him sneezing is a process that can't be learnt. One can fake sneeze but a real sneeze is outside human control. Similarly emotions are also passive like sneezes which are outside of voluntary control and are associated with patterns of bodily change. According to Fredrickson, [12] emotions are important as they broaden attention and create situations where cognitive, physical, and social resources can be built. She studied positive emotions and found that joy promotes play, which helps to build physical, social, and intellectual skills. Similarly, contentment broadens the self and worldview and creates the urge to integrate; love triggers other positive emotions and solidifies individual and social resources.

Monitoring emotions is important as it contains information that can help in improving human wellbeing. It is also important to monitor emotions as they are perceptions of bodily changes and can help in identifying matters of concern at an early stage before they become more serious. Emotion regulation is an important skill for coping with social and personal problems [13]. Emotion recognition has also become an important subject in human-machine interaction in present times. Various methods have been used in the past to detect human emotions. The most commonly used techniques are explained in detail.

2.1 Emotion Recognition Using Text

Emotion recognition using text has become popular these days, especially when it comes to human-machine interaction. Textual information is not only an important communication medium which exists in books, newspapers, websites, emails etc, but also a rich source of emotion [14]. Different approaches have taken place in order to recognize and evaluate these emotions. The most common approach uses natural language processing techniques, which extract emotions and sentiments by analyzing the input text. Zhang *et al.* [15] developed a semi-automatic acquisition technique to obtain emotion information using a sentence or text. They constructed a Chinese language emotion thesaurus in which words had its own classification (such as commendatory, derogatory) and the corresponding emotion information. Their emotion recognition system was able to analyze the textual input, including sentence and paragraph to obtain the emotion information such as the emotion value and category of emotion. Similarly, Li *et al.* [14] developed a three-dimensional (3D) emotion space to identify the text emotional orientation visually and intuitively. They built an emotion dictionary based on the emotion corpus containing information of eight basic emotions. The emotion keywords behaved as distributions of 3D structure and were projected into the emotion space.

Matsumoto *et al.* [16] designed an emotion estimation system to create an affective robot which can recognize emotion based on language information obtained from words in conversations. The system extracts emotion occurrence condition based on emotions contained in words and sentence meanings, and estimates the emotion of a speaker or writer. The materials used for the system are collected from written quotations, conversations and internet blogs. Wu *et al.* [17] used a pattern matching method to find the negative implications resulting from negative words in Chinese sentences. They collected sentences containing negative words and emotion information from the web to construct a corpus. They summarized and structured negative auxiliary modifiers vocabulary, degree adverbs vocabulary and causative verbs vocabulary for the process of matching. This method

provided a new train of thought to deal with the problem of emotion recognition in negative sentences and achieved a high precision recognition.

Li *et al.* [18] designed an emotional chatting system incorporating personality factor. The participants were asked to chat with the emotional chatting machine. The recorded results from the chat were then read by another machine which followed basic emotion reasoning rules. In the end, the accuracy of the both the machines were evaluated by the participants. Similarly, Kalra and Karahalios [19] presented a system called TextTone, for the explicit expression of emotion in online textual communication. It incorporated reader-specific preferences for the visualization of tone and emotion. According to them, affective analysis of textual emotion can contribute towards sentiment analysis, computer assisted creativity and verbal expressivity in human-computer interaction.

Calix *et al.* [20] focused on automatic emotion detection in descriptive sentences and used it to tune facial expression parameters for 3-D character generation. They compared manual and automatic word feature selection approaches to determine the influence of word features on classification accuracy using support vector machines (SVM). Similarly Boucouvalas [21] designed a real-time communication interface which enhanced text communication detected from a real-time typed text. The extracted emotions of the communicating subjects were displayed as facial expression images or sketches on the screen. The interface made use of a developed real-time emotion extraction engine from text.

Danisman *et al.* [22] studied the automatic classification of anger, disgust, fear, joy and sad emotions in text on the ISEAR (International Survey on Emotion Antecedents and Reactions) dataset. They used Vector Space Model for classification of emotions and valences in text. The results were then compared with other powerful text based classifiers and showed better performance for emotion detection in sentences. Strapparava and Mihalcea [23] also studied the automatic analysis of emotions in text for six basic emotions: anger, disgust, fear, joy, sadness and surprise, and proposed and evaluated several knowledge-based and corpus based methods for the automatic identification of emotions in text.

From the above literature review, it can be seen that emotion recognition using text is applied to words or sentences in a particular language. This is a major drawback when it comes to developing a universal system. This approach can be useful to many researchers, however in this project we are interested in developing a universal system that can recognize emotions automatically rather than by speaking, typing or writing.

2.2 Emotion Recognition Using Facial Expressions

Facial emotion recognition plays a vital role when it comes to developing multi-cultural visual communication systems for emotion translation between cultures. As we know, computers and robots are being used widely for betterment of our daily life therefore it is important for computers and robots to have an artificial mind that would enable them to communicate with human beings using both logical and emotional information [24]. Emotion recognition using computers can also be applied to psychological counselling and therapy which can help in the detection of criminal and antisocial motives [25]. The basic idea of emotion recognition using facial expression is to segment facial images into various regions of interest. The common regions taken into account include movements of cheek, chin, wrinkles, eyes, eyebrows, and mouth. Different classification techniques are then applied to differentiate between different types of emotions. Cowie *et al.* [26] developed an intelligent emotion recognition system, interweaving psychological findings about emotion representation with analysis and evaluation of facial expressions. They created a fuzzy rule based system for classification of facial expressions to the six archetypal emotion categories. The continuous 2-D emotion space was then examined and a pool of known and novel classification and clustering techniques were applied to the collected data resulting in high rates of emotion classification. Similarly, Chakraborty *et al.* [25] presented a fuzzy relational approach to human emotion recognition from facial expressions and its control. Their proposed scheme used external stimulus to excite specific emotions in human subjects whose facial expressions were analyzed by segmenting and localizing the individual frames into regions of interest. Selected facial features such as eye opening, mouth opening, and

the length of eyebrow constriction are extracted from the localized regions, and mapped onto an emotion space by employing Mamdani-type relational models.

Yang and Bhanu [27] created an emotion avatar image (EAI) as a single representation for video or image sequences for emotion recognition. They used scale-invariant feature transform (SIFT) flow algorithm to align the face images which is able to compensate for large global motion while maintaining facial feature motion detail. They then used an iterative algorithm to generate an avatar reference face model onto which each face image is aligned. For feature extraction they used both local binary pattern (LBP) and local phase quantization (LPQ). Based on their results they concluded that the performance of facial recognition is dramatically improved by using single EAI representation compared with the baseline approach. Similarly Valstar and Pantic [28] designed a fully automated system for fast and robust facial expression recognition from face video. They analyzed subtle changes in facial expression and their temporal behaviour by recognizing facial muscle action units. These action units helped in the detection of facial expressions of emotions, attitudes and moods from facial signals in a face video. A fully automatic facial localization method is used to detect 20 point of interests in the first frame of an input face video. Support vector machine, trained on a subset of most informative spatio-temporal features, is used for recognition of temporal segments and muscle action units

Matsumoto and Willingham [29] on the other hand studied the expressions of congenitally and non-congenitally blind athletes in the 2004 Paralympics games and compared them with each other and with those produced by sighted athletes in the 2004 Olympic Games. They also examined how expressions change from one context to another and found that there were no differences between congenitally blind, non-congenitally blind, and sighted athletes, either on the level of individual facial actions or in facial emotion configurations. Blind athletes did produce more overall facial activity, but these were isolated to head and eye movements.

Emotion recognition using facial expressions has many advantages, but we know that facial expressions can be consciously controlled. This means that a happy

person can display an angry face or any other expression, which shows that facial expressions are not always linked with inner emotions. For this reason, this approach for emotion recognition has been disregarded in this project.

2.3 Emotion Recognition Using Speech

Speech contains information that is not limited to what is being said but it also contains information like speaker's emotion, real intention and meaning [30]. Emotion recognition from speech has become increasingly popular as it has become an important part of affective computing and can help in improving human-machine interaction. It can also be used in applications like call centre conversation analysis, entertainment, indexing of audio files based on emotions and so on [31]. Various methods and interfaces have been designed to detect emotions from speech signals. Razak *et al.* [32] designed a system named voice driven emotion recognizer mobile phone for automatic recognition of emotion in speech. They used linear predictive coding algorithm for feature extraction and selected 18 speech features to represent each emotion. English and Malay were the languages used for training and recognition purpose. Similarly Giannakopoulos *et al.* [33] used speech data information from movies for emotion recognition. They investigated the use of emotion wheel for representation of emotions associated with speech signals and used regression approach to predict the location of an unknown speech segment in the emotion wheel.

Koolagudi *et al.* [34] proposed a method using linear prediction (LP) residual and zero frequency filtered speech signal for epoch parameters extraction to recognize emotions present in speech. They define 'epoch' as the instant of glottal closure within pitch period of LP residual. According to them the significant excitation of vocal tract usually takes place at the instant of glottal closure. They used strength of epoch, instantaneous frequency, sharpness of epochs, and slope of strength of epochs as the features for classification of emotions which were extracted from the glottal closure region of LP residual. For analyzing emotion recognition, they used the proposed epoch parameters, actor recorded Telugu

database and Berlin emotional database. They considered six emotions namely anger, disgust, fear, happy, neutral and sadness. They achieved average emotion recognition of 61% and 58% for their models using support vector machine and Gaussian mixture model classification methods. Similarly, Pao *et al.* [35] studied emotion recognition using whole sentence segmentation method and detected the emotion transition point from the continuous speech. They investigated five emotions, including anger, happiness, sadness, boredom, and neutral and employed two classification algorithms, the conventional K-nearest neighbor (KNN) and weighted discrete-KNN (WD-KNN), in the recognition phase. Their results yielded an average recognition rate of 73% for the used testing sentences.

Kamaruddin and Wahab [36] attempted to find the correlation between driver behaviour state (DBS) and speech emotion states (angry, happy, sad and neutral). They used three different classifiers i.e. Multi Layer Perceptron, Adaptive Neuro Fuzzy Inference system and Generic Self-organizing Fuzzy Neural Network coupled with Mel Frequency Cepstral coefficient features extraction method and achieved accuracy of 70%. They found that sleep DBS was consistently recognised as sad emotion and this was due to the fact that both emotions shared the same negative value of the activation axis in the affective state model. On the other hand, Tokuno *et al.* [37] investigated emotions from voice data collected from the personnel of military medical corps participating in a special stressful mission. They used sensibility technology for emotion voice analysis system which is capable of determining emotional elements including anger, joy, sorrow, calmness and excitement. The results suggested that the implementation of proper techniques of emotion recognition can help in screening of mental status in military situations.

The above literature review provides information about the importance and benefits of emotion recognition using speech. It is a non invasive and simple way of emotion recognition based on the tone of speech signals. We know that tone of speech varies with different cultures, a person from a certain culture or area, talking in a normal tone might sound angry to someone from another culture due to the speed and volume of conversation. On the other hand talking in a low and slow tone

might be viewed as a sad emotion in one culture but polite and normal in another. Therefore emotion recognition systems based on speech would be specific to certain cultures or areas rather than being universal.

2.4 Emotion Recognition Using Body Movements and Gesture

Body movement and gesture is another way of expressive communication. Recent research show that features of some emotions exist in whole body posture and movement quality [38]. Various methods and techniques have been used to extract these emotions, which will help in improving human-machine communication. Ginevra *et al.* [39] proposed an approach for the recognition of four acted emotional states (anger, joy, pleasure, and sadness) based on the analysis of body movement and gesture expressivity. They used non-propositional movement qualities, i.e. amplitude, speed and fluidity of movement, to infer emotions and investigate the role of movement expressivity versus shape in gesture. Their proposed method analyzed emotional behavior based on direct classification of time series and on a model that provides indicators describing the dynamics of expressive motion cues.

Camurri *et al.* [40] worked on the analysis and classification of expressive gesture in human full-body movement and in particular dance performances. Their experiment aimed at individuating motion cues that were mostly involved in conveying the dancer's expressive intentions to the audience during a dance performance. These movements were measured and analysed in order to classify dance gestures in term of basic emotions using a collection of developed models and algorithms. Spectator ratings for performance of the same dance fragments were compared. Their results showed that spectators were able to detect the intended emotions that were transmitted during performances of the same dance movements with grief performances receiving the highest recognition rate, followed by anger and then joy. Performances of fear received a comparatively lower recognition rate. Similarly, Boone *et al.* [41] investigated the general ability to decode happiness, sadness, anger and fear in dance forms of expressive body movement in children and

adults. They found that four year old children demonstrated above chance decoding of sad expressions while five year old children clearly distinguished between emotions of happiness, sadness, and fear.

Kipp and Martin [42] studied the relation between emotion and gestural features on a corpus of theatre movies. They used pleasure, arousal and dominance (PAD) dimensions as their coding scheme for emotions. For gestural features they analysed handedness, hand shape, palm orientation and motion direction. They compared material of two different actors acting in the same role and found significant correlations between handedness and emotion. They found that for both actors, the right hand was used in conjunction with negative and aggressive feelings whereas the left hand was used more when in a relaxed and positive mood. On the other hand Kapur *et al.* [43] used full body skeletal movements captured using video-based sensor technology developed by Vicon Motion Systems, to train a machine to identify different human emotions. The system used a series of six cameras to capture lightweight markers placed on various points of the body in 3D space, and digitized movement into x, y, and z displacement data. Gestural data collected from five subjects depicted four emotions i.e. sadness, joy, anger, and fear.

Emotion recognition based on body movements and gestures is the least popular way of evaluating emotions. This method evaluates emotions based on specific actions or dances assigned and naturally occurring, which is one of the major drawbacks. Emotion recognition from body movements and gestures has some benefits, however in this project it has only been studied for literature review purposes.

2.5 Emotion Recognition Using Physiological Signals

Emotion recognition using biosensors has recently become popular not only in human-human interactions but also in human-machine interactions. Biosensors have the advantage of monitoring physiological parameters of the body that are directly controlled by the autonomous nervous system which are affected by emotions. These sensors can collect signals including heart rate, skin conductance,

electrocardiogram, blood volume and temperature, and evaluate emotions based of the changes taking place. Another popular signal for evaluating emotions is by the use of electroencephalography which monitors the electrical activity of the brain. Different clustering and evaluating techniques are then used to relate physiological changes and emotions. Healey and Picard [44] developed a method for collecting and analyzing physiological data during real-world driving tasks to determine a driver's relative stress level. Electrocardiogram, electromyogram, skin conductance, and respiration were recorded continuously while drivers followed a set route through open roads in the Boston area. Data from 24 drives of at least 50min duration were collected for analysis. Their results showed that skin conductivity and heart rate metrics were most closely correlated with driver stress level which indicated that physiological signals can provide a metric of driver stress in future cars capable of physiological monitoring. Similarly, Zhai and Barreto [45] developed a stress detection system based on the physiological signals monitored by non-invasive and non-intrusive sensors. They monitored four signals, i.e. galvanic skin response, blood volume pulse, pupil diameter and skin temperature, and analyzed the collected data to differentiate affective states in a computer user. They used support vector machine to perform classification of various states and found that the monitored physiological signals had a strong correlation with changes in emotional state when stress stimuli was applied with pupil diameter having the most significant affect as compared to the other signals. Sierra *et al.* [46] also proposed a stress detection system based on physiological signals. Galvanic skin response and heart rate were used to provide the physiological information of an individual. They designed specific psychological experiments to induce stress on individuals in order to acquire a database for training, validating and testing the proposed system. Fuzzy logic was used as the basis to describe the behavior of an individual under stressing stimuli, in terms of HR and GSR. They achieved as 99.5% accuracy in stress detection from HR and GSR signals during a period of 10 seconds.

Kim and André [47] designed an automatic emotion recognition system using music data. Data was collected from multiple subjects over many weeks using musical induction method. Four biosensors were used to measure electromyogram,

electrocardiogram, skin conductivity, and respiration changes. Linear discriminant analysis was performed to classify four musical emotions i.e. positive/high arousal, negative/high arousal, negative/low arousal, and positive/low arousal. Their system showed a recognition accuracy of 95% and 70% for subject-dependent and subject-independent classification respectively. Similarly, Takashi [48] studied computational emotion recognition using multi-modal bio-potential signals. Two vital signs, pulse and skin conductance response, were measured to evaluate three emotions i.e. positive emotion (relax and pleasure), negative emotion (stressful and un-pleasure), and normal. Audio contents were used to excite emotions in subjects and bio-potential signals were observed. They used support vector machine design for computational emotion recognition and achieved 41.2% recognition rate for the three emotions.

Maaoui and Pruski [49] worked on emotion recognition using physiological signals obtained from multiple subjects. International affective picture system images were used to extract target emotions. Five physiological signals, blood volume pulse, electromyography, skin conductance, skin temperature and respiration, were selected to extract 30 features for recognition. Two pattern classification methods, fisher discriminant and support vector machine method were used and compared for emotional state classification. The experimental results indicated that the proposed method provides very stable and successful emotional classification performance. Khalili and Moradi [50] also used signals from electroencephalogram, galvanic skin resistance, temperature, blood pressure and respiration to observe the influence of emotion on the central nervous system and autonomic nervous system. The acquisition protocol was based on a subset of pictures which correspond to three specific areas of valance-arousal emotional space. From their results, they found that EEG signals performed better than other physiological signals.

Yang and Chao [51] used accelerometer and physiological sensors, attached to an arm band, to recognize user's activity. They used fuzzy Bayesian network for

continuous sensor data analysis and found that using physiological signals with accelerometer is more efficient in recognizing user activities.

The above literature review shows the importance of emotion recognition based on data from physiological sensors. This approach has gained considerable popularity compared to other emotion recognition methods, as it collects information from the physiological changes of the body. Physiological changes are controlled by the autonomous nervous system which is affected by emotions, therefore in this project we have considered this approach as it provides information about the internal emotions of a subject rather than just physical changes. The physiological sensors used in this project are non-invasive, low cost, reliable, and power efficient with the ability to monitor data in a comfortable and unobtrusive manner.

3.0 Project Overview

The developed system consists of three physiological sensors, signal conditioning circuitry, a microcontroller, ZigBee modules and a computer. The three sensors used in this project are heart rate sensor, skin temperature sensor and skin conductance sensor. The heart rate sensor and skin conductance sensor have been designed in the lab. The raw signals from these sensors are filtered and amplified using signal conditioning circuit. The conditioned signals are then input into the digital and analogue ports of the microcontroller where it carries out the required processing and transmits it to serial port. From this point onward, the data can be transmitted to the computer via RS232 cable or ZigBee wireless technology. The data is transmitted by the microcontroller using a ZigBee router which is received at the other end by a ZigBee coordinator. The coordinator is connected to the computer via USB. The data received by the coordinator is then displayed on the computer using software designed for data storage, analysis and emotion recognition. Figure 3.1 shows the block diagram of the developed system.

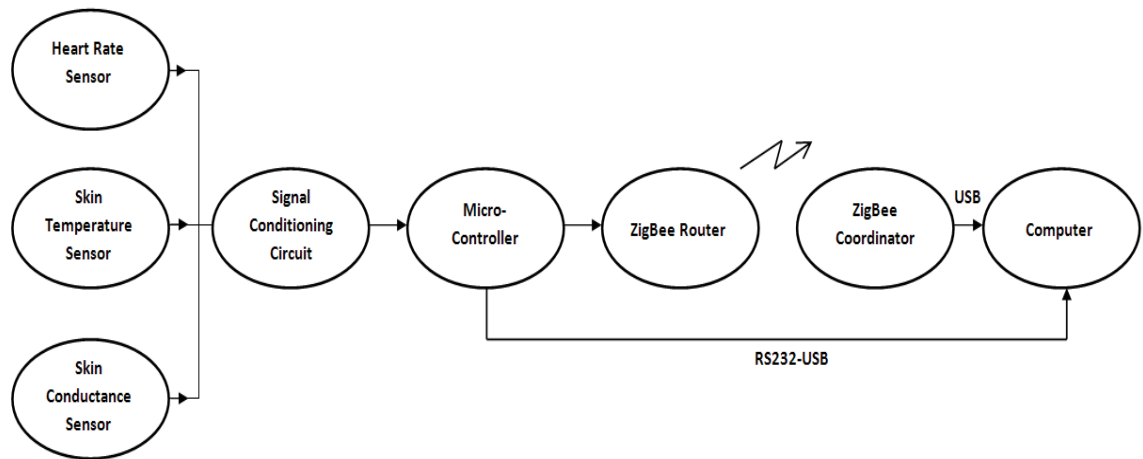


Figure 3.1: Block diagram of the developed system.

The designed software carries out data analysis for emotion recognition using k-means clustering technique. The four emotions (states) observed by the system are happy (excited), sad, angry and neutral (relaxed). These observations are based on

the training data collected from 14 healthy subjects with ages ranging from 19 to 72 years. The details are explained in the results and discussion section 8.0.

The developed system is mainly aimed at offices, school, universities, and other institutions where wellbeing of computer users can be improved by continuous monitoring of emotions. The system can be used by anyone sitting within a range of 30m of a computer. This project is also a part of a bigger project known as “Integrated home management system for the elderly” where it will be used for monitoring the physiological signals along with the emotions of the elderly.

The main objectives of this project are to design a real time monitoring system which is capable of evaluating four basic emotions i.e. happy, sad, angry and neutral using physiological sensors. These sensors should be non-invasive and capable of monitoring data in a comfortable and unobtrusive manner. The system has to be affordable. The designed software and hardware should be easy to maintain, modify and upgrade. The system has to be capable of wirelessly communicating with a computer in order to monitor data without being attached to the computer.

4.0 Heart Rate:

4.1 Introduction

The human heart is a pumping organ that helps in supplying blood and oxygen to all parts of the body [52]. It is divided into four chambers. The upper two chambers are called the atria and lower two chambers are called the ventricles as shown in Figure 4.1.

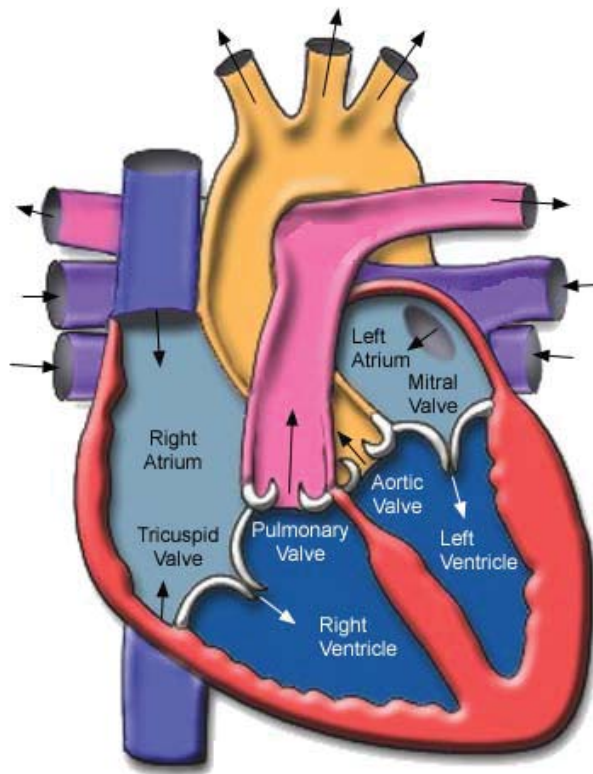


Figure 4.1: Anatomy of human heart [53].

All these chambers are connected with each other through heart valves. The atria are separated into left and right atrium by an interatrial septum. The main function of the atria is to receive deoxygenated blood returning from all parts of the body. Similarly, the ventricles are also separated by interatrial septum into left and right ventricles. The ventricles are responsible for pumping oxygenated blood, received from the atria, to all parts of the body. As this blood is pumped throughout the body, it produces a pulse in the arteries. This pulse is a direct representation of the number of times the heart beats. In an average adult, the heart goes through a

full cardiac cycle 70 times a minute [54]. This means that a healthy heart rate at rest is 60-80 beats per minute (BPM). There are a number of events that take place during a heartbeat. These events can be seen on a typical electrocardiogram (ECG) and are called QRS complex. Figure 4.2 shows the generated QRS signal.

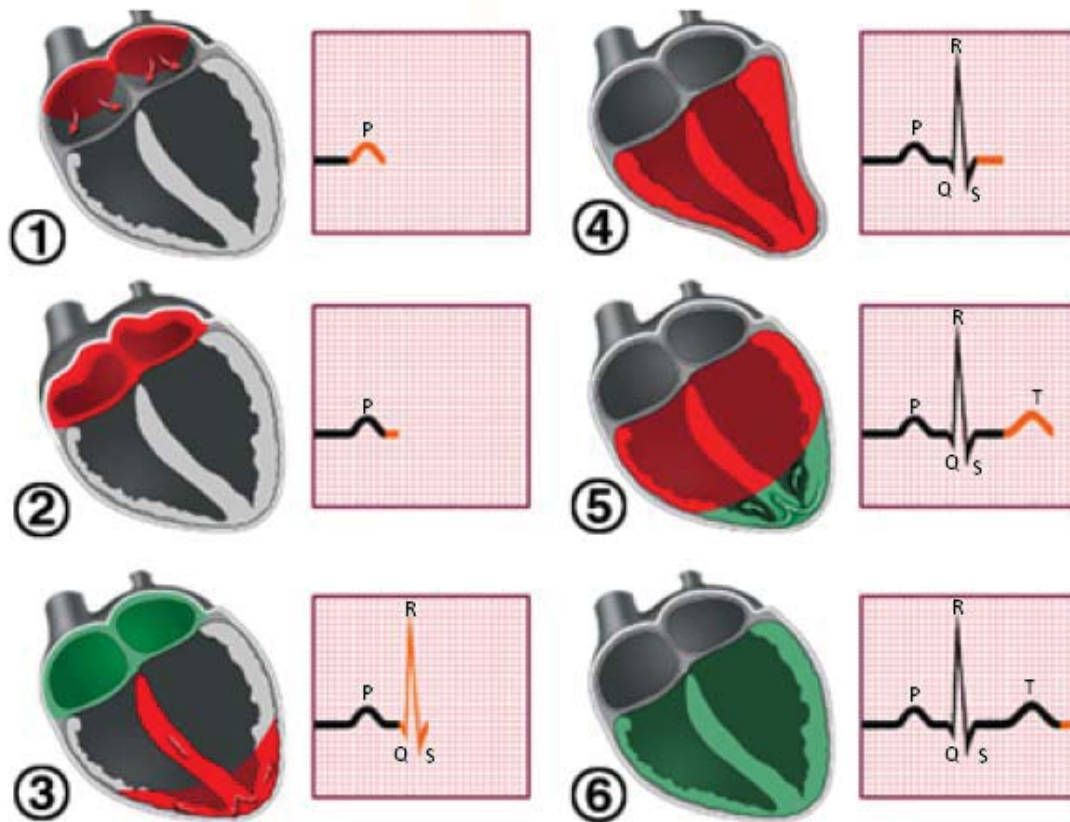


Figure 4.2: Heartbeat signals produced by the heart [55].

The events that take place during a heartbeat are as follows.

1. Atria begin to depolarize
2. Atria depolarize
3. Ventricles begin to depolarize. Atria repolarize
4. Ventricles depolarize
5. Ventricles begin to repolarize
6. Ventricles repolarize

There are a number of factors that cause irregularities in heart rate. The most common heart rate variability at rest can be due to serious heart problems, respiratory problems and emotional imbalance i.e. stress, panic attacks, anxiety and depression. In this project we are interested in finding relationship between heart rate and emotions.

The importance of heart rate variability has been well known for decades now. According to Saul [56] the normal variability in heart rate is due to autonomic neural regulation of the heart and the circulatory system. The degree of heart rate variability provides important information about the functioning of the nervous system. Similarly, according to Armour [57-59], the heart has a network of several types of neurons, neurotransmitters, proteins and support cells that are similar to the ones found in the brain. For this reason, he called the heart as a 'little brain'. His research also revealed that the heart has its own intrinsic nervous system that operates and processes information independently of the brain or nervous system.

Paul *et al.* [60] studied the variations in cardiac vagal control among coronary patients and found that the variations were due to cardiovascular responses to behavioural stress. Similarly, McCraty [61] in his research observed a dramatic change in the pattern of heart's rhythm due to changes in autonomic activity. He found that emotions such as anger, frustration or anxiety caused the heart rhythms to get more erratic and disordered as compared to highly ordered heart rhythms observed from positive emotions such as love, appreciation or compassion.

The above research provides enough evidence to prove that heart rate and emotions are related, therefore we chose heart rate as one of our signals in our project to help in differentiating between different emotions.

4.2 Heart Rate Measurement

Various techniques and devices have been used to measure heart rate in humans. The main techniques include the use of pressure sensors/accelerometers, sound/acoustic sensors and light sensors. The pressure sensors measure the pressure changes near the heart or vibrations produced by heart. The sound sensor

measures the changes in sounds near the heart while light sensors detect changes in optical property of blood. The details of the above techniques and researches done by various scientists and engineers are explained as follows.

4.2.1 Heart rate measurement using accelerometer/pressure sensors

One of the most commonly used techniques to measure heart rate is by using pressure sensors/accelerometer. Pressure sensors are used to detect pressure changes and vibrations near the heart area. Many researchers have used this method to observe resting heart over a long period of time. Okada *et al.* [62] used an acceleration system to measure resting heart rate over long term. The system was placed inside a down quilt close to left side of the chest. The mechanical vibrations from the heart activity were carried to the acceleration sensor and the results showed that there was a high correlation with R wave of electrocardiograph (ECG). They also found that their method reduced the psychological and physical burden on the subject during resting heart rate measurement throughout long period as compared to ECG. Similarly Wang *et al.* [63] used pressure sensors to transform vibration caused by heart beats into electrical signals. They obtained Ballistocardiograph (BCG) and ECG signals from 30 young men and after analysis they found that the heart rate signal deduced was the same as one channel ECG. However their system did not use any electrodes and it could be worn with normal clothes without the subjects noticing. Yamamoto *et al.* [64] also used an air pressure sensor to design a functional assessment system of autonomic nervous system. The air pressure sensor was placed under the mattress and detected changes in heart rate. They used fuzzy membership function and found that the detected inter-beat intervals had a correlation coefficient of 0.85 when compared with electrocardiograph.

Morillo *et al.* [65] on the other hand presented a body-fixed sensor approach to assess potential sleep apnea patients. Accelerometer was used to acquire the vibration produced by the heart. The sensor was fixed with a noninvasive mounting on the suprasternal notch of subjects resting in supine position. Heart rate, heart

rate variability and other biomedical parameters for new sleep apnea diagnosis strategies were calculated, for 15 patients with sleep apnea disorder, and compared to those obtained by polysomnography and an accurate microphone. Their system showed good results and proved that accelerometer based devices can contribute towards screening of sleep apnea–hypopnea syndrome and other breathing disorders. Dinh *et al.* [66] also designed and tested a heart rate sensor using a low cost accelerometer. The design was based on the seismocardiography (SCG) signals generated by the activity of the heart and blood flow acting on the chest wall. Their results proved that SCG based sensors can successfully sense and collect human heart beat.

Pressure sensors are a popular way of heart rate measurement. This approach is common for monitoring people in lying state with the sensor closer to the heart (around the chest area). Flexibility and sensitivity to external noise and movements are a few of the major drawbacks of this approach therefore the use of pressure sensor has been discarded in this project for heart rate measurement.

4.2.2 Heart rate measurement using sound/acoustic sensors

Another popular approach used for measuring heart rate is by sound, also known as phonocardiography. It is a non-invasive and reliable way of heart rate monitoring with minimal constraints to patients [67]. The activity of heart muscles, valves and blood flux produces sounds and vibrations which can be detected by piezoelectric transducers. This method is popular as it does not require many wires and a single probe collects the required information. A number of researchers use this technique for heart rate monitoring. Zhang *et al.* [68] used sound signals received from a microphone to measure heart rate. The design used an air conductive microphone and an efficient algorithm to estimate the heart beat parameters of the subject without coming in direct contact with the skin. Similarly Scanlon [69] developed an acoustic sensor pad technology that was useful for combat casualty care and soldier performance monitoring. They detected heartbeats, breaths, motion, and other physiological sounds related to injured and

uninjured soldiers. The detected sounds were then transmitted, and analyzed for diagnostic purposes. The acoustic sensor pad was a fluid-filled bladder with a hydrophone that coupled well to the soldier's torso. The pad acted as a fluid extension of the body to form an acoustical conduit to a sensitive hydrophone within the pad that detects body sounds. Acoustic analysis of the sensor-pad output provided amplitude, phase, frequency, duration, rate, and correlative information that would be useful for medical diagnosis, patient care, and research. Data collected with the prototype device showed excellent signal-to-noise ratios for heart and breath sounds.

Sound signal is one of simplest and easiest ways of measuring heart rate. However to measure heart rate using sound, external noises have to be minimized which is one of the major drawbacks of this approach. Therefore the use of sound signal based heart rate sensor has been avoided.

4.2.3 Heart rate measurement using light:

Light source has become popular in the field of pulse oximetry. It is a non-invasive method for measuring heart rate and other physiological parameters of body. This method uses light emitting diodes (LEDs) in the near infrared region and a photodiode which detects change in blood volume. Many researchers have used this method to monitor heart rate and blood oxygen level because of its simplicity, small size and noninvasiveness. Wong *et al.* [70] designed a near-infrared (NIR) heart-rate sensor IC for portable biomedical application. Their sensor consists of a current-to-voltage (I-V) converter, sample-and-hold (S/H) circuit, continuous time low-pass filter (CT-LPF), comparator and clock generation circuitry. Their design was fabricated using 0.35um CMOS technology and simulation results showed that the circuit had the least power consumption when compared with other LED heart rate sensors. Similarly Patterson *et al.* [71] presented a novel ear-worn reflective photoplethysmography (PPG) sensor. Their aim was to minimize ambient noise artifacts and couple the sensor to the surface of the skin. Light emitting diode (LED) modulation and a unique integrating photocurrent demodulator reduced

susceptibility to wideband noise and allowed subtraction of ambient light from the desired PPG signal. Their experimental results showed that the sensitivity of the sensor is robust to location and pressure variations. Hashem *et al.* [72] also proposed a heart rate measuring (HRM) device using optical technology to detect the flow of blood through index finger. They evaluated qualitative and quantitative performance of the device on real signals. These signals showed accuracy in heart rate estimation, even under intense physical activity. The performance of HRM device was compared with electrocardiogram reports and manual pulse measurement of heartbeat of 90 human subjects of different ages. The results showed that the error rate of the device was negligible.

Yoo and Lee [73] worked on stress assessment based on pulse photoplethysmography (PPG). They assessed the possibility of using the pulse rate variability (PRV) extracted from the PPG signal as an alternative measurement of the heart rate variability (HRV) signal. They compared the accuracy and feasibility of HRV extraction from PPG signal, finger-tip PPG and standard lead II ECG signals. Their results showed that PRV based on PPG could be used as a surrogate of HRV for the purpose of stress assessment.

Heart rate measurement based on optical sensors has recently become popular due being noninvasive, low cost, compact, simple and having reliable data output, therefore this approach has been applied in this project for monitoring heart rate.

4.3 Heart Rate Sensor

The heart rate sensor used in this project is based on the principle of photoplethysmography (PPG). PPG is an optical measurement technique used for detecting blood volume changes in the micro vascular bed of tissue [74]. This method uses a light source (LED) which illuminates the skin and a light detector (photo diode) that detects the changes in optical properties due to change in blood volume. This method has become very popular in the medical field especially in pulse oximetry due its simple, non-invasive and unobtrusive monitoring. In clinics PPG is

also used for monitoring other physiological parameters i.e. blood oxygen saturation, blood pressure, cardiac output and respiration. However, in this project it has only been used for monitoring the heart rate.

In order to measure the heart rate, PPG can be used in two different ways. One way is to have the light detector and light source on the same side of the skin, this is called reflectance PPG. Reflective PPG works by illuminating a bed of capillaries, typically with light in the infrared range due to its low absorption by tissue, before measuring how the back-scattered light is modulated by the blood [71]. This method is suitable for long term comfortable monitoring however it is sensitive to movements and other noises. The other way is to have light detector and light source placed across the skin; this is called transmittance PPG [75]. Transmittance PPG usually occurs at the extremities of body including fingertips, toes and earlobes due to large density of capillaries. In this project transmission PPG is used as it is more reliable, resistant to movements and external noise and also provides a comfortable monitoring of heart rate at the extremities of the body.

Once we decided to use transmittance PPG technique for measuring the heart rate, the next step was to build a low cost sensor to serve the purpose. In order to build the sensor, the first step was to choose the right light source and light detector. In this project we use a 940nm Optek OP180 LED. The OP180 is a Gallium arsenide (GaAs) infrared LED mounted in plastic leadless PLCC-2 SMD package with a flat lens window that allows for wide beam angles [76]. The main reasons for using the OP180 LED is because it has low power consumption, has flat lens for comfortable contact with skin, and is low cost. For light detection, we used SDP8406 phototransistor by Honeywell. The SDP8406 is an NPN silicon phototransistor molded in a side-looking clear plastic package and has a wide accepting angle [77]. The reason for choosing SDP8406 is its low cost, low power consumption and its spectral response which is suitable for accepting 940nm wavelength radiation from the OP180. Figure 4.3 shows both LED and phototransistor.



Figure 4.3: Infrared LED (OP180) and phototransistor (SDP8406).

After choosing our LED and phototransistor the next step was to design and build the electronic circuit of the heart rate sensor. The circuit schematic was designed using Altium design software. The circuit consists of two high pass filters and three operational amplifiers. The first two operational amplifiers were used to amplify the raw signal while third one was used as a comparator. A low power quad operational amplifier (LM324) has been used for signal amplification. Figure 4.4 shows the circuit schematic designed in Altium designer.

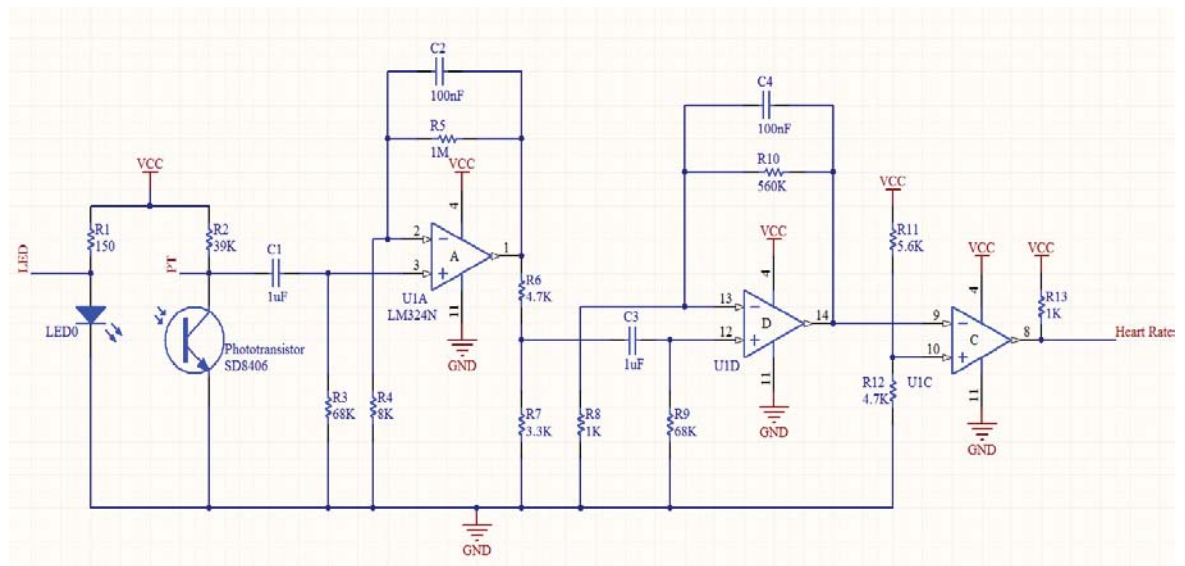


Figure 4.4: Schematic of the heart rate sensor

The circuit was built using a breadboard for testing purpose. Figures 4.5 and 4.6 show the PPG signal produced at the phototransistor and the digital heart rate signal produced respectively, observed by an oscilloscope.

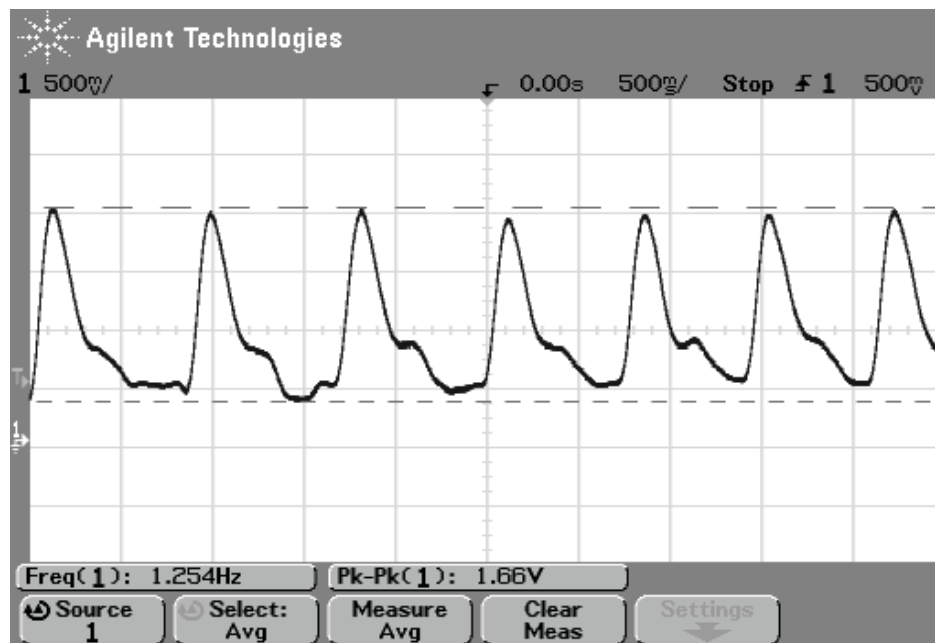


Figure 4.5: PPG signal detected at the photo transistor.

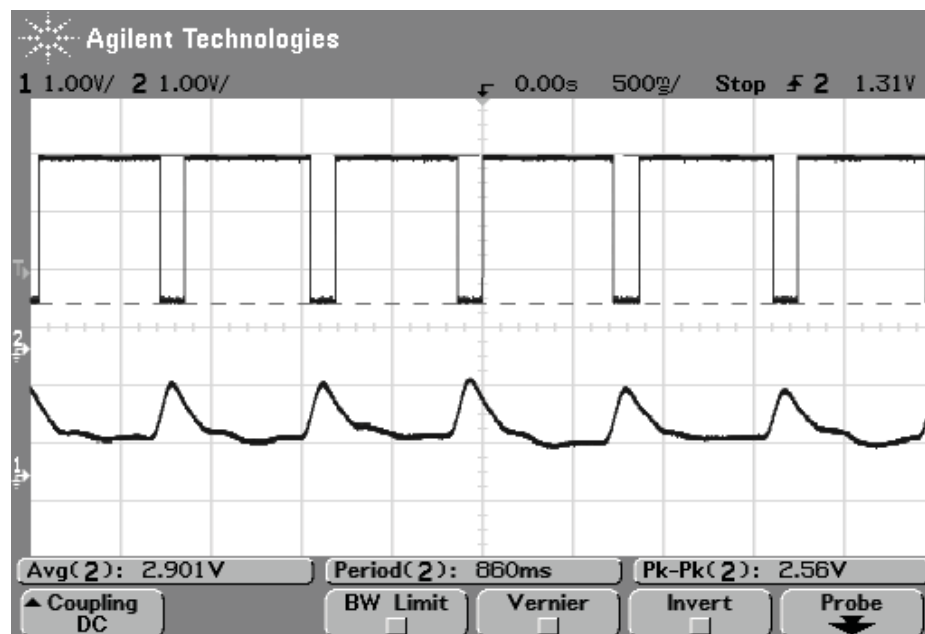


Figure 4.6: PPG signal (bottom) and converted digital signal (top).

During testing it was observed that the outputs were sensitive to motion. We also observed that putting pressure on the fingers due to the LEDs being wrapped

too tight around the finger caused the BPM to rise. Keeping these constraints in mind, it was important to design a casing for the LED and phototransistor. This would help in reducing the effect body movements and also reduces the pressure when they are placed across the finger. A simple casing was designed using SolidWorks. Figures 4.7 and 4.8 show the casing designed in SolidWorks and placement of LED and phototransistor on the casing respectively.

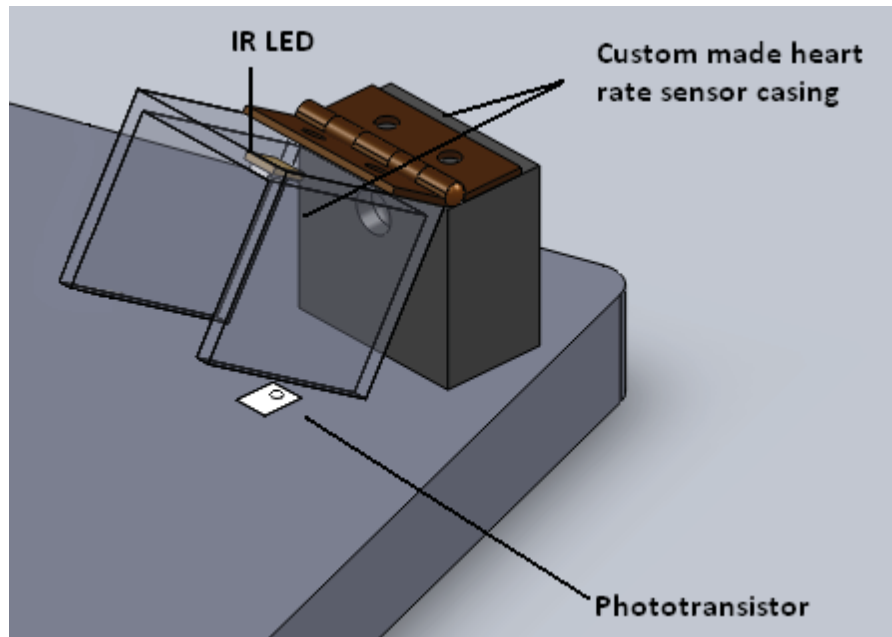


Figure 4.7: Casing 3D model in SolidWorks

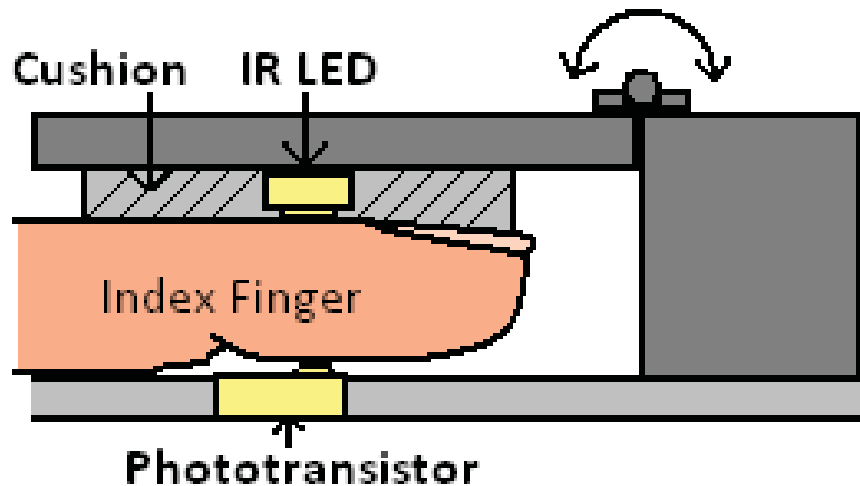


Figure 4.8: Position of IR LED and photodiode

The casing for the heart rate sensor was designed slightly larger than an average index finger. Once the design was finalised, the next step was to machine the casing. The casing was machined from plastic using conventional machining while the hinge was obtained from a hardware store. The casing of the heart rate sensor is shown in figure 4.9.

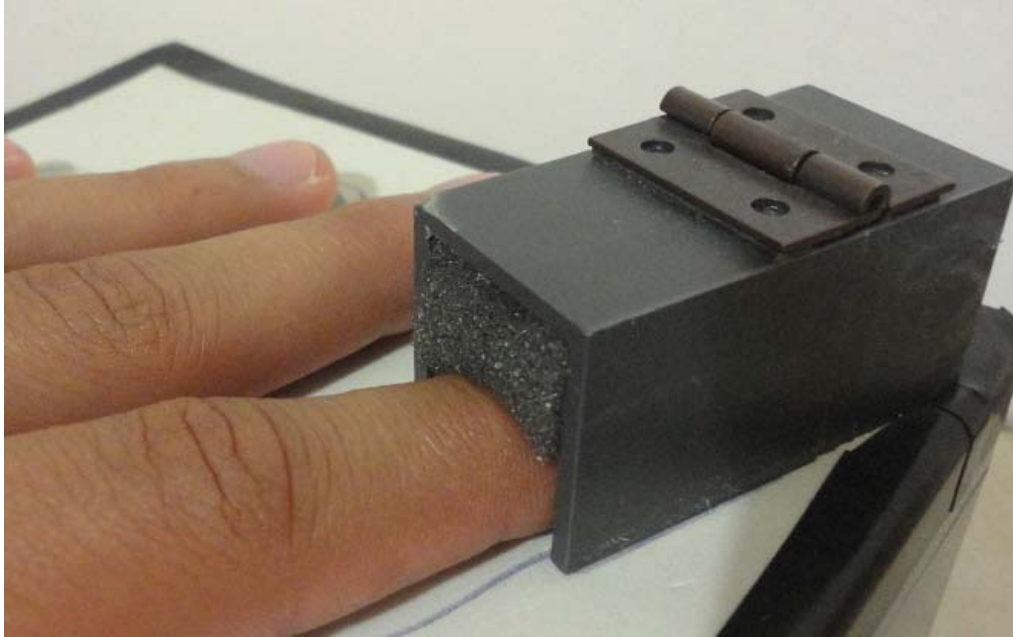


Figure 4.9: Heart rate sensor casing.

Once the casing for the heart rate sensor was built, the next step was to integrate the IR LED and phototransistor with the casing. An extension spring was installed for the return action of the casing top. For cushioning effect, a piece of sponge was used where the LED and finger came in contact. The design proved to be more resistant to bodily movements and was more comfortable in monitoring as per feedback from participants.

The digital signal from the heart rate sensor is then input into the digital port of the microcontroller where all the processing takes place for beats per minute (BPM) value calculation. This is explained in the heart rate calculation section 4.4. The data from the heart rate sensor is then displayed using the designed software. The software also has the option of storing the data as an excel file for future reference. This is explained in the Graphical user interface (GUI) section 7.6. Once we

were satisfied with the BPM signal from HR sensor, the next step was to test the BPM values with another heart rate sensor. The BPM values obtained were compared with a commercially available pulse oximeter to test the reliability and consistency of the BPM values as they will play a vital role in analysis of emotions. Figure 4.10 shows a comparison of BPM values of the designed HR sensor and the commercial pulse oximeter.

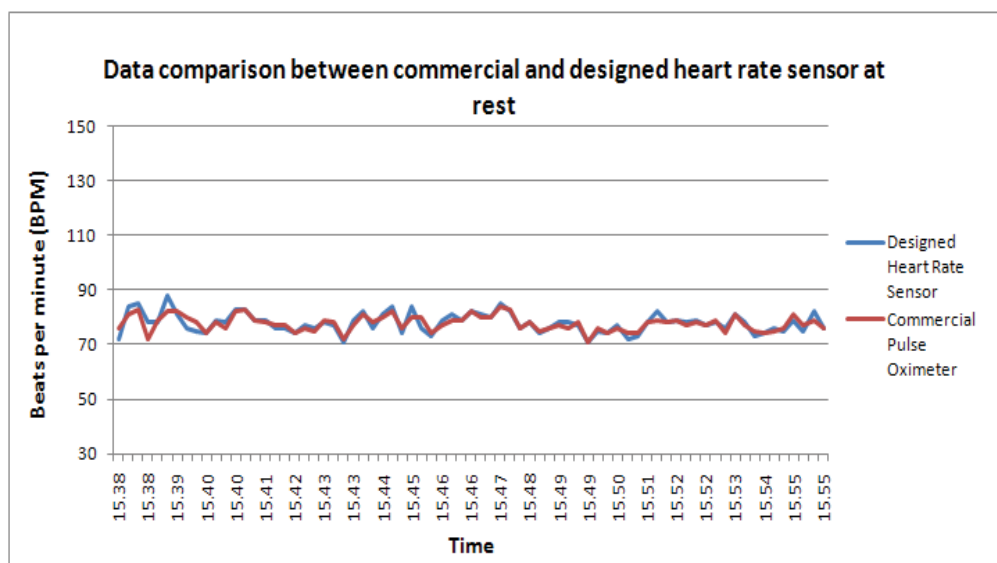


Figure 4.10: Heart rate sensor comparison

As seen from the above comparison, the BPM values from the designed HR sensor are quite similar to those of the pulse oximeter for a period of approximately 15mins. These values were also compared with manual pulse observation and found the average to be same. The above comparisons proved the reliability and accuracy of the BPM values of the designed HR sensor. From this point onwards the BPM data was used for data monitoring and emotion recognition.

4.4 Heart rate (BPM) Calculation

As stated earlier, the conditioned signal from the heart rate sensor is input into the digital port of the microcontroller. The microcontroller takes care of all the processing and the calculation of BPM value. In order to calculate the BPM value, the appropriate code was written in SiLabs IDE. The code can be seen in the appendices section 13.0.

The digital heart rate signal from the sensor is input into digital port 0 pin 2 of the microcontroller. Timer 0 is programmed in 8-bit auto-reload mode (mode 2) so that it overflows at a regular interval and generates an interrupt at 10μsec intervals. Figure 4.11 gives a rough idea of how this works.

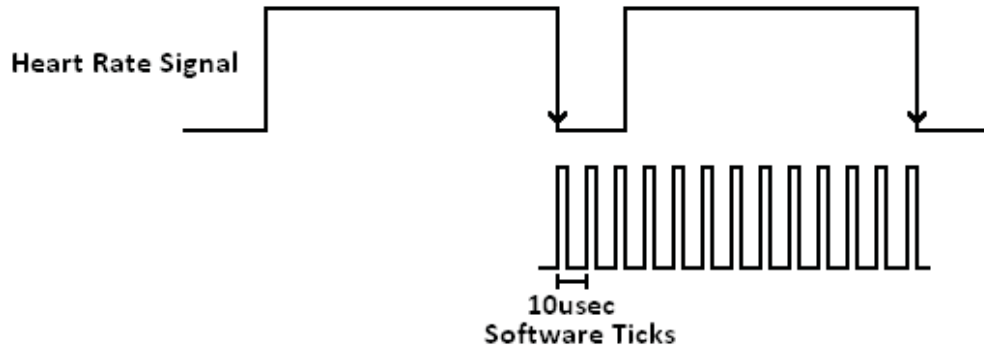


Figure 4.11: BPM measurement technique

In order to generate interrupts at 10μsec interval, the reload value for Timer0 had to be calculated for a system clock of 22.1184MHz. Timer0 low byte (TL0) operates as an 8-bit timer while the timer high byte (TH0) holds the reload value. When the count in TL0 overflows from FFH to 00H, the timer flag is set and the value in TH0 is loaded into TL0. The TL0 and TH0 values have to be initialized. The TL0 value is set to 0xFF while TH0 value requires calculation. In order to calculate the value of TH0 we need to find the time period of the system clock which can be calculated using equation (1).

$$T_{SysClk} = \frac{1}{F_{SysClk}} \quad (1)$$

Where

F_{SysClk} : System clock frequency, 22.118400 MHz

i.e.
$$T_{SysClk} = \frac{1}{22.118400 \times 10^6 \text{ Hz}} = 0.04521 \text{ μsec}$$

After calculating the T_{Sysclk} value, reload value for Timer0 (TH0) can be calculated using the following.

$$\# \text{ SysClk pulses} = \frac{10\mu\text{sec}}{0.04521\mu\text{sec}} \cong 221$$

$$\text{Timer reload value} = 255 - 221 = 34$$

$$\text{TH0} = 0x22 \text{ (34)}$$

Once timer0 reload value was calculated for generation of software ticks, the next step was to count the number of ticks between two successive heart rate pulses. In order to achieve this, BPM_Tick_Counter is incremented in the Timer 0 interrupt service routine (ISR) every time a tick is generated. The pulses from HR sensor are used to generate an external hardware interrupt at INT0. The number of ticks between two falling/negative edges of the heart rate signal is stored in INT0 ISR as BPM_T_count_value. The final BPM value is calculated using equation (2).

$$\text{BPM} = \frac{K}{\text{BPM_T_count_value}} \quad (2)$$

Where

$$K = 6000000, (60/T_{\text{tick}})$$

$$T_{\text{tick}} = 10\mu\text{sec}$$

The BPM_Tick_Counter is programmed to ignore BPM values smaller than 40 BPM and larger than 170 BPM as this provides a good range of maximum and minimum BPM values for normal human beings. These BPM values are then put into a string with other parameters and transmitted via the serial port which is then displayed, stored and analysed for emotion recognition. Data transmission is explained in the serial communication section 7.2.

5.0 Skin Temperature

5.1 Introduction

The human skin is an organ made up of a layer of tissues that protect underlying muscles and organs. As skin comes in direct contact with the surroundings, it plays a vital role in protecting the inner body from external threats. The skin is the largest organ of the human body as it covers the whole body and has the largest surface area. It weighs more than any single organ of the body [78]. The skin has two major layers, the epidermis and the dermis. These layers are made of different types of tissues and have different functions. The epidermis is the outermost layer and is responsible for keeping water in the body and keeping other harmful chemicals and pathogens out. The dermis lies below the epidermis and contains a number of structures that are responsible for lubrication, water-proofing, softening and anti-bactericidal actions. The other main function of the skin is to regulate body heat by controlling evaporation and excretion.

Skin temperature is an effective indicator when it comes to evaluating human sensations. Kataoka *et al.* [79] investigated the relationship between stressful tasks and the skin temperature. They found that skin temperature falls when stress, tension or other sensations occur, because blood flow decreases due to factors like blood vessel constriction. This was most noticeable at extremities such as fingertips and nose. Similarly according to Blessing [80] the net heat transfer between the individual and the external environment varies according to the amount of blood flowing through the skin, which is regulated as an intrinsic component of body temperature control. The non-metabolic factor influencing cutaneous blood flow is a sympathetically-mediated vigorous vasoconstriction initiated when the individual perceives a potentially dangerous environmental event.

Yamakoshi *et al.* [81] studied driver's awareness level using skin temperature. They measured facial skin temperature, including truncal and peripheral site, of healthy volunteers during simulated monotonous driving. They found that sympathetic activity, peripheral vasoconstriction, was increased during monotonous

driving situation which resulted in a significant gradual drop in peripheral skin temperature. Rimm-Kaufman *et al.* [82] on the other hand studied the effect of the psychological incentive on the magnitude and direction of temperature changes on the face and hands. They studied thirty-two female undergraduates who were presented with varied, mildly stressful incentives and recorded the temperatures of their face and hands with infrared telethermography. They observed an increase of hand skin temperature to film clips intended to generate a happy affect but a decrease to threatening personal questions. They also found a larger temperature change on the hands than on the face.

The above research provides sufficient evidence to prove that the nervous system and skin temperature are related. Due to this reason we chose skin temperature signal as one of our input signal for emotion evaluation in this project.

5.2 Temperature Measurement

Various equipment and instruments have been used in the past for body temperature measurement. The most common device to measure temperature is a thermometer. Thermometer is made from two Greek words thermo which means heat and meter which means measure. Therefore, a thermometer is a device that detects change in temperature and converts it into a temperature value [83]. There are different types of thermometers. The most common ones include mercury-in-glass, infrared, gas, plastic strip and liquid crystal thermometers. However, mercury-in-glass thermometers have widely been used for clinical purpose. Other devices used for measuring temperature include thermocouples, thermistors, resistance temperature detector (RTD) and silicon band gap temperature sensors. All these temperature measuring devices are designed to measure temperature for specific objects or environments. Thermocouples are widely used in industries for measuring temperatures as high as 5000°F and are less suitable for measuring temperature where accuracy is important [84]. Similarly thermistors are used in a lower temperature range and are often used automobile applications, fire alarms and

other electronic circuit temperature monitoring. RTDs on the other hand are temperature sensors where high precision and accuracy is important.

Temperature can be measured using different scales. The most common temperature scales used and accepted internationally are the Kelvin or Absolute, Centigrade or Celsius and Fahrenheit scale. The comparison of these scales is given in Table I.

Table I: Temperature scales comparison [85].

Temperature	Kelvin (K)	Celsius (°C)	Fahrenheit (°F)
Absolute Zero	0	-273.15	-459.67
Melting point of ice	273.15	0	32
Average human body temperature	310.15	37	98.6
Boiling point of water	373.15	100	212

In this project a silicon band-gap temperature sensor has been used. These types of temperature sensors are widely used in electronic equipment where continuous temperature monitoring is essential. These sensors have a silicon diode whose forward voltage is temperature dependent. Integrated circuit (IC) type temperature sensors are low cost yet accurate and reliable. The output voltage is transformed into a temperature value using a mathematical formula depending on the type of IC. The reason for using this type of sensor is because we are continuously monitoring the skin temperature of a human being. Therefore it was considered more appropriate due to its exposed pad which will come in direct contact with the skin and help in easy and comfortable monitoring of skin temperature. The details of the sensor are discussed in the temperature sensor

section below. We have consistently used the Centigrade scale for skin temperature measurement in this project.

5.3 Temperature Sensor

As we know there are a number of devices available for monitoring or observing human temperature. In our case, we wanted to go for a low-cost, compact, reliable and accurate temperature sensor capable of monitoring skin temperature with ease and comfort. We chose DS600 by Maxim - Dallas semiconductor for skin temperature monitoring in this project. The DS600 is an analog-output temperature sensor which is inexpensive, compact, has low power consumption, and is sufficiently accurate. One of the main features of the DS600 IC is that it has an exposed pad which will be in direct contact with the skin of the person being monitored, in real time. The pin configuration of the sensor is shown in figure 5.1.

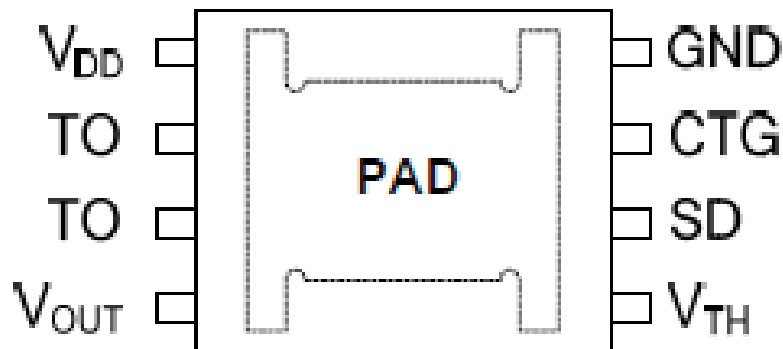


Figure 5.1: Pin configuration of DS600.

The DS600 IC requires 2.7 - 5.5V to operate which is provided by the microcontroller. It provides an accuracy of $\pm 0.5^{\circ}\text{C}$ over a range of -20 to 100°C [86]. This range and accuracy is sufficient for our real time monitoring and emotion analysis. The output from the sensor is an analog voltage which is proportional to temperature in degree Centigrade. The conversion of the voltage into a temperature value is explained in the temperature calculation section 5.4. The output characteristic of DS600 is shown in figure 5.2 below.

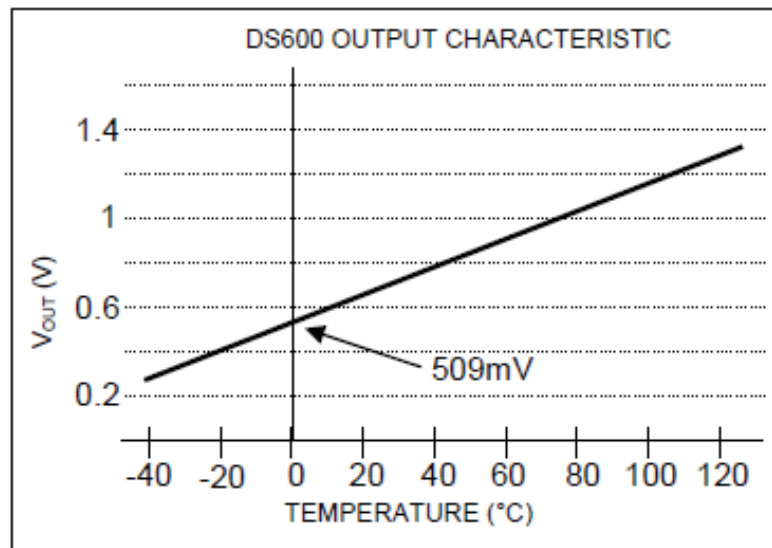


Figure 5.2: Output voltage characteristic of DS600 [86].

Once DS600 temperature sensor was selected for skin temperature monitoring, the next step was to test the sensor data. In order to test the sensor the ICs had to be soldered on to printed circuit boards (PCBs). The circuit was designed using Altium designer and modified in a way such that temperature detecting pad would be facing outwards. Figure 5.3, 5.4 and 5.5 below show the circuit diagram and PCB in Altium design software, and the PCB produced.

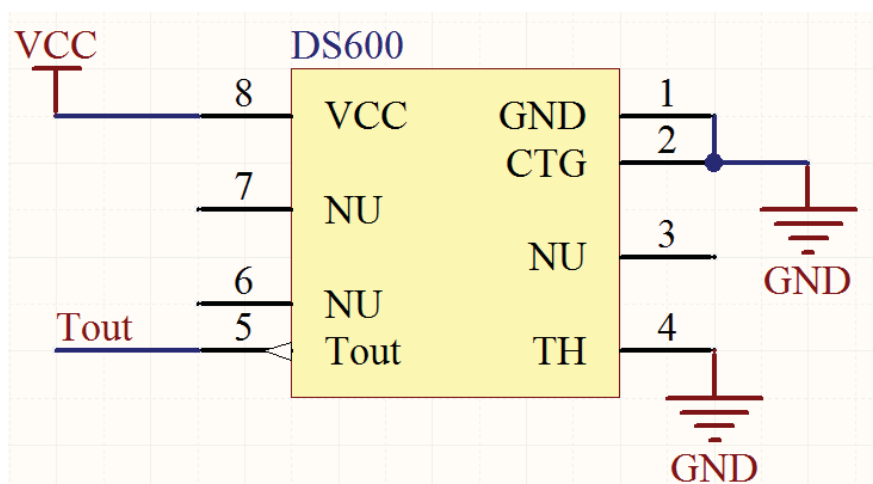


Figure 5.3: Temperature sensor circuit design in Altium Designer



Figure 5.4: PCB design of temperature sensor in Altium designer

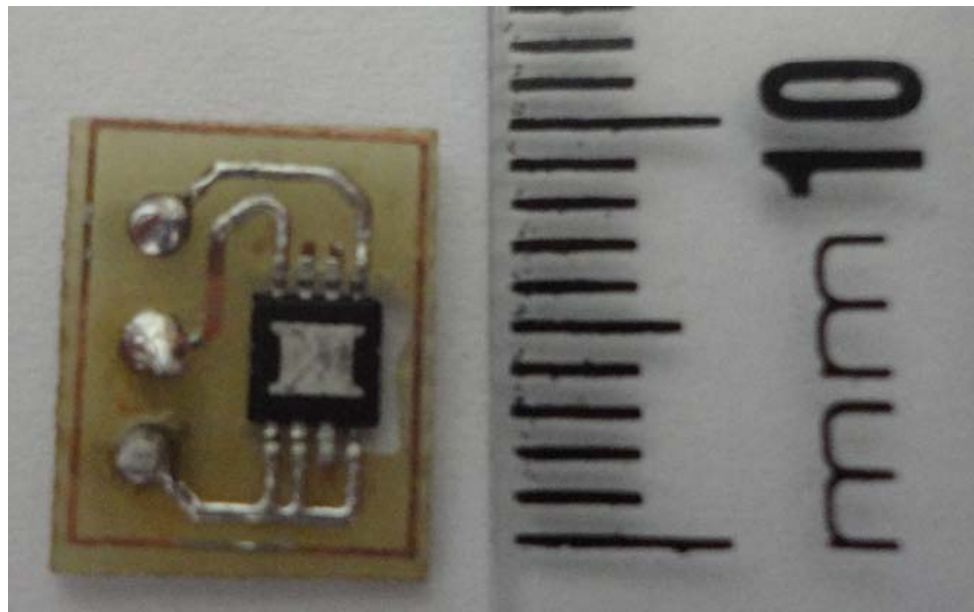


Figure 5.5: Printed circuit board of temperature sensor

Once the circuit was designed and the IC soldered on to the PCB, it was then tested against another thermometer. The output from the DS600 temperature sensor was tested and compared with Fluke 51K/J thermometer. Figure 5.6 and 5.7 show the temperature signal from both Fluke 51K/J thermometer and the DS600 temperature sensor at room temperature and body temperature respectively.

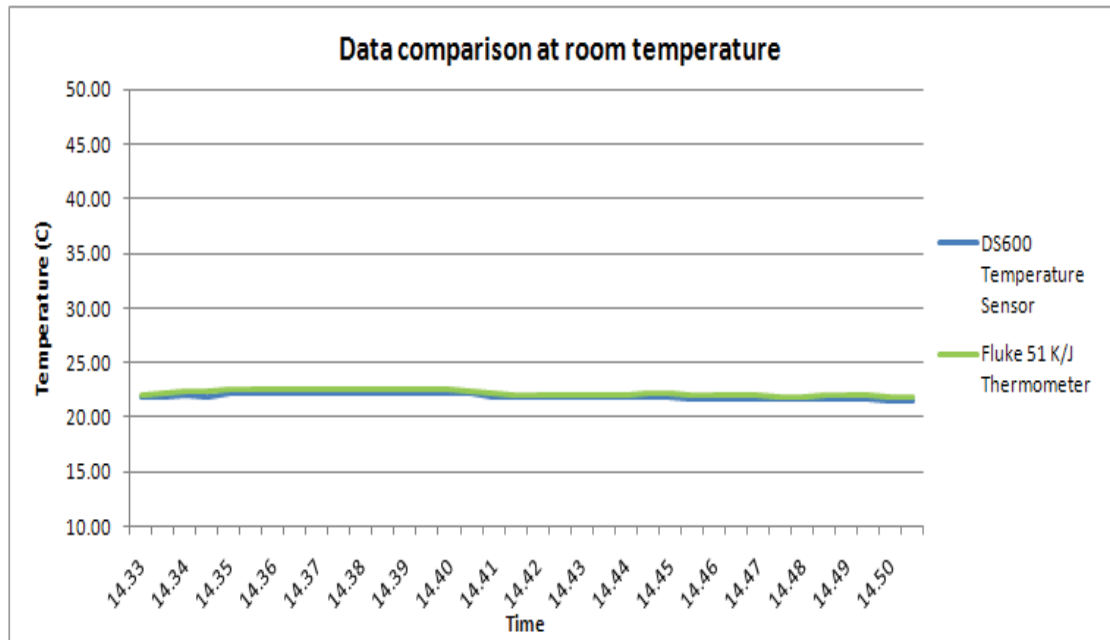


Figure 5.6: Temperature sensor comparison at room temperature

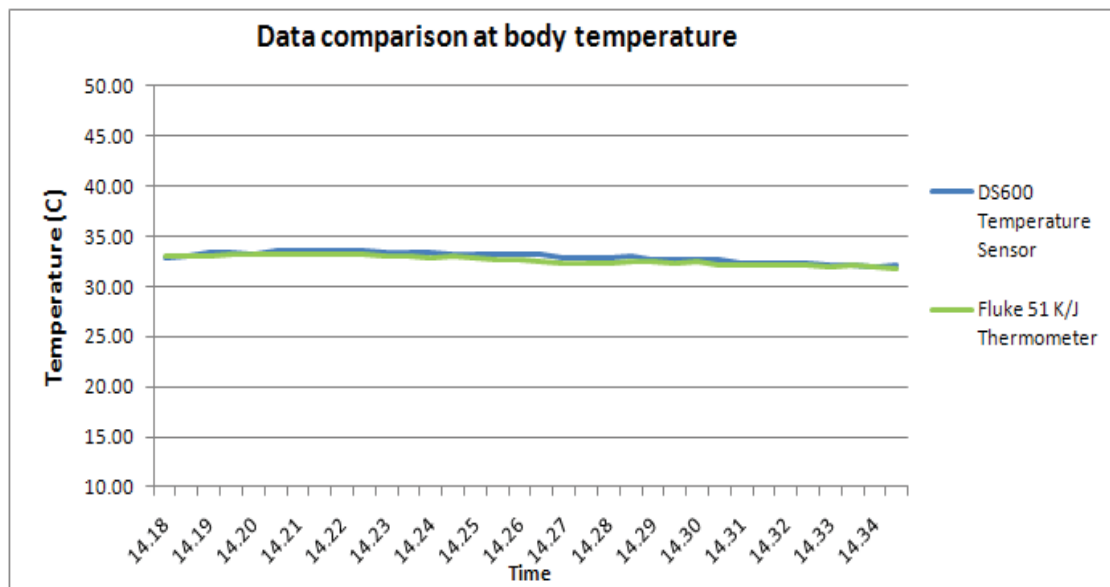


Figure 5.7: Temperature sensor comparison at body temperature.

The above comparison proved the reliability and accuracy of the DS600 temperature sensor. It was then decided to use the sensor for data monitoring and emotion recognition. The next important task was the placement of the sensor for skin temperature monitoring. As the data is collected only from the left hand, the sensor had to be placed in a way such that it would be in continuous contact with the skin. For this reason it was decided to measure temperature from the palm rather than the fingers. Another reason for choosing the palm is because the

sympathetic innervations of the arteriovenous anastomoses are densely distributed on the palms [87]. Figure 5.8 below shows the placement of temperature sensor on the system.

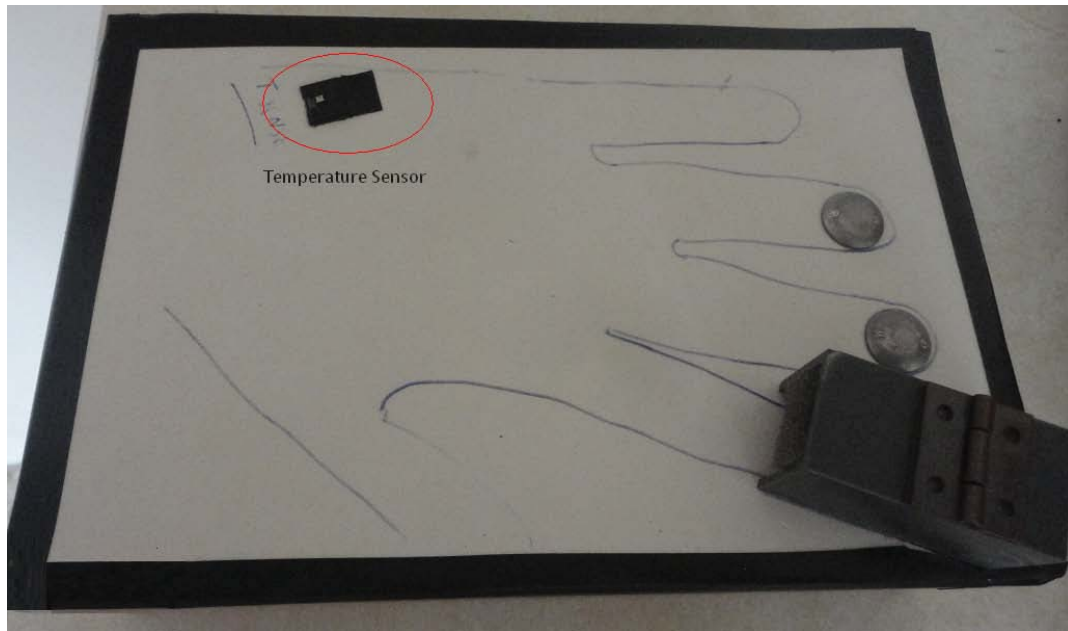


Figure 5.8: Skin temperature sensor placement on the system.

In the current design the temperature sensor is placed below the palm under the flexor digiti mini brevis muscle. This surface of the palm is soft and stays in good contact with the temperature sensor pad and does not affect the readings, when small movements occur.

5.4 Temperature Calculation

As stated earlier, the output from the temperature sensor is an analog voltage. This output signal from the sensor is input into the analog port pin 1 of the microcontroller. The microcontroller is programmed to perform the required processing and conversion from a voltage value into a temperature value using SiLabs IDE. The signal processing in SiLabs IDE is explained in the analog signal processing section 7.5 of the report as it is common for all analog signals. The relationship between voltage value and temperature value is given by the following equation:

$$T(^{\circ}\text{C}) = \frac{V_{out}-V_{os}}{\Delta V/\Delta T} \quad (3)$$

Where

V_{os} = DC offset, 509mV

$\Delta V/\Delta T$ = Typical output gain, +6.45 mV/ $^{\circ}\text{C}$

The above equation is used in the program to convert a voltage value into a temperature value. This temperature value is added to a string along with other signals and transmitted via the serial port. This data is then used for data analysis and emotion recognition. Data analysis and emotion recognition is explained in the results and discussion section 8.0.

6.0 Skin Conductance

6.1 Introduction

The study of physiological effects due to electrical changes in human skin began over 100 years ago. Féré [88] found that, by passing a small electrical current across two electrodes placed on the surface of skin, one could measure momentary decrease in skin resistance in response to a variety of stimuli. In other words, skin became a better conductor of electricity when external stimuli were presented. Similarly Tarchanoff [89] reported that one could measure changes in electrical potential between two electrodes placed on the skin without applying external current. Therefore Féré and Tarchanoff are said to have discovered the two basic methods of recording electrodermal activity in use today.

The skin is a selective barrier that serves the function of preventing entry of foreign matter into the body and selectively facilitating passage of materials from the bloodstream to the exterior of the body [90]. There are two forms of sweat glands in the human body; the apocrine and the eccrine. The latter one is of primary interest to psychophysicologists. The primary function of the eccrine sweat glands is thermoregulation. However, according to Edelberg [91], the sweat glands on the palmar and plantar surfaces are more responsive to psychological sweating than other areas. Figure 6.1 below shows the anatomy of the eccrine gland and various layers of skin.

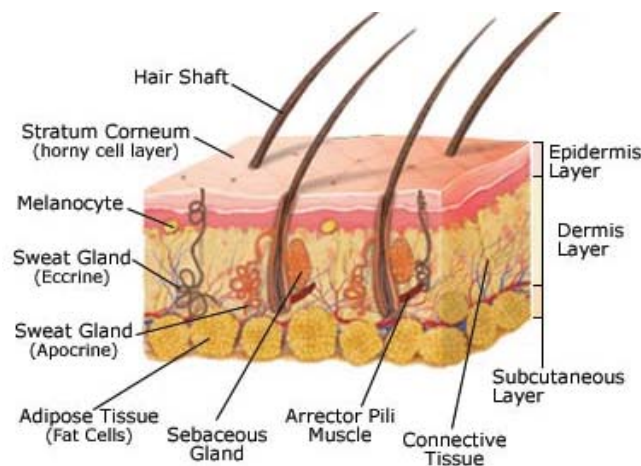


Figure 6.1: Skin Anatomy [92]

The skin has electric properties that change relatively quickly and are closely related to psychological processes [93]. These changes in electrodermal activity (EDA) and skin conductance are related to changes in eccrine sweating. As sweat is an electrolyte, the more the skins sweat ducts and pores are filled with sweat, the more conductive the skin becomes. The sympathetic branch of the autonomic nervous system (ANS) controls eccrine sweating, thus skin conductance reflects the arousal of the sympathetic ANS which accompanies various psychological processes. EDA and skin conductance have been used in a wide array of research, serving as indicators of such processes as attention, habituation, arousal, and cognitive effort in many different sub domains of psychology and related disciplines. In judgment and decision making (JDM) research, skin conductance is often used as an indicator of affective processes and emotional arousal.

Various terms have been used in literature to refer to various aspects of electrodermal activity and skin conductance. The term electrodermal activity (EDA) was introduced by Johnson and Lubin [94] in 1966 and refers most generally to all (passive and active) electrical phenomena in the skin, while skin conductance is one form of EDA. Specifically, the term skin conductance refers to how well the skin conducts electricity when an external direct current of constant voltage is applied.

In this project we use the term skin conductance response (SCR) which is the measure of change in output voltage when a small input voltage is applied. Two electrodes are used to measure skin conductance at the finger tips as they are easily accessible and can collect data unobtrusively and reliably. Also eccrine sweating on the volar surfaces is different from other locations, as sweating in these skin parts is strongly related to mental processes rather than thermoregulation [95]. The details of the SCR sensor are discussed in the skin conductance response sensor section 6.3.

6.2 Skin Conductance Measurement

Nowadays there are a number of devices used for measuring skin conductance. Most of them follow a similar principle by keeping the current constant and measuring the change in voltage or by keeping the voltage constant and

measuring the current. However, constant-voltage skin conductance systems have gained more popularity for direct measurement of skin conductance [90]. These products are easily available in the market however they are quite expensive. Therefore, in this project we decided to design a simple skin conductance sensor that is cheap, sufficiently reliable, has low power consumption and capable of monitoring data in a comfortable and unobtrusive manner.

Skin conductance is usually measured in micro Siemens (μS) which is the reciprocal of resistance. However in this project, skin conductance is measured in millivolts (mV). As discussed earlier, this value is directly related to the level of arousal. The skin conductance signal is input into the analog port pin 7 of the microcontroller. The details of sensor are explained in the skin conductance response sensor section below.

6.3 Skin Conductance Response Sensor

Skin conductance response (SCR) is measured by passing a small current through a pair of electrodes placed on a surface of skin. The measured value can be in the form of resistance, conductance, voltage value or current value. In this project, the skin conductance sensor went through a few design modifications. The initial design consisted of three operational amplifiers. The non-inverting inputs of two amplifiers were connected to the electrodes while the inverting inputs were connected with each other through a resistor. The third operational amplifier was used as a comparator. The output from this setup was a voltage value in millivolts. Figure 6.2 shows the circuit diagram of the initial design.

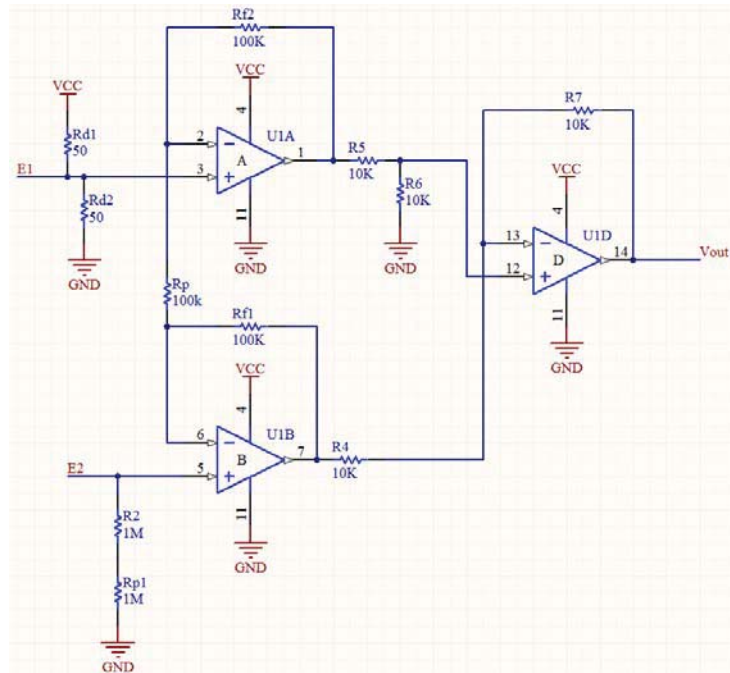


Figure 6.2: Initial circuit diagram for SCR sensor

The second circuit is based on a simple voltage divider circuit. Fig 6.3 shows the circuit diagram of the SCR sensor.

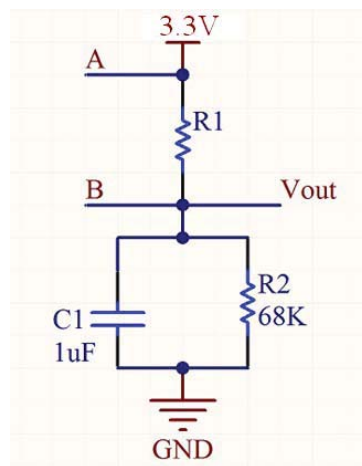


Figure 6.3: Final circuit diagram of SCR sensor

As we can see from the schematic, the circuit is powered by 3.3V. The microcontroller supplies the required voltage. R_1 is the electrical resistance of the human body where the human body acts as a large resistor. As discussed earlier, this resistance is dependent upon the level of arousal. A and B are two electrodes that will stay in contact with the human skin. In this project these electrodes are stainless steel screws and will come in direct contact with the middle and ring finger. These

screws are attached on to the top of the system box for easy and comfortable access as shown in figure 6.4. Initially strap type electrodes were chosen but it was observed that the level of tightness of the strap had an effect on the outcome for the SCR values and it is more inconvenient in comparison to the screws. Therefore the idea of using strap electrodes was ignored.

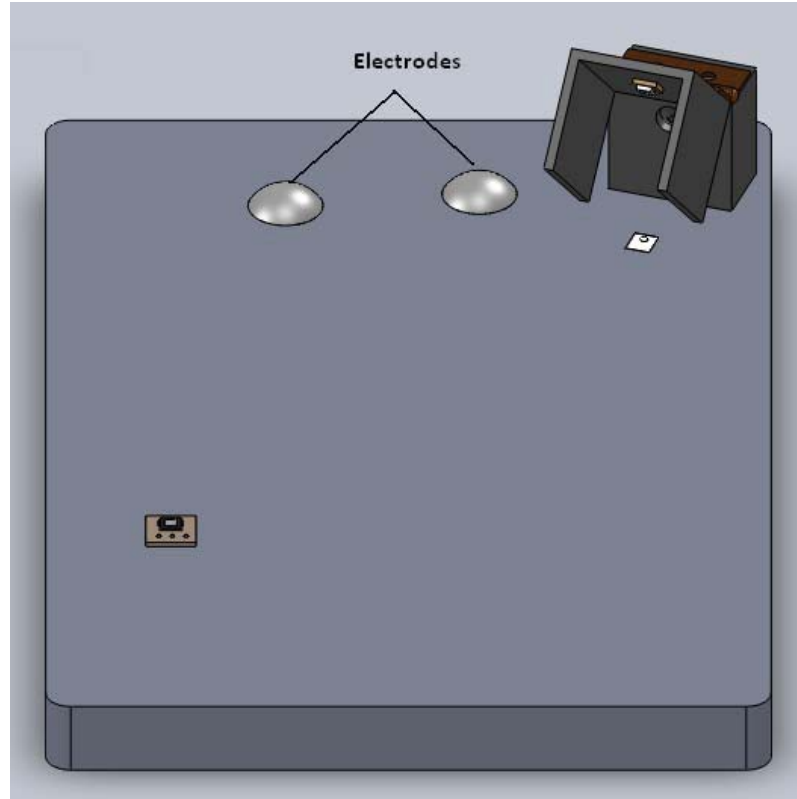


Figure 6.4: Position of electrodes on the surface.

C_1 is a $1\mu\text{F}$ capacitor, and R_2 is a $68\text{K}\Omega$ resistor. As we know from voltage divider formula (4) the V_{out} is only dependent on the value of R_1 , as R_2 and C_1 are kept constant.

$$V_{\text{out}} = V_{\text{in}} \cdot \frac{R_2 \parallel C_1}{R_1 + R_2 \parallel C_1} \quad (4)$$

Equation (4) shows that V_{out} and R_1 have an inverse relationship, therefore when the value of R_1 decreases V_{out} increases and vice versa. As we know from earlier discussion, R_1 decreases with an increase in the level of arousal and vice

versa. Therefore theoretically this circuit works. Once the sensor was designed, the next step was to test it. The circuit was tested on a bread board and the values for R_2 and C_1 were decided depending on the sensitivity level required. The circuit showed good data output and sensitivity level.

In this project, the latter design was selected as it contained fewer components and had better data output compared to the initial circuit. Once the design and signal output was approved the next step was to build the PCB, combine it with the rest for circuit and connect the output from the sensor into the microcontroller. The output signal from the microcontroller was input in the analog port pin 7. The microcontroller was programmed to process the analog signal which is explained in the analog signal processing section 7.5. The SCR values are stored as a string and transmitted via the serial port along with other signal for data analysis and emotion recognition. Figure 6.5 and 6.6 gives a rough idea of subject monitored in relaxed and happy (excited) state respectively.

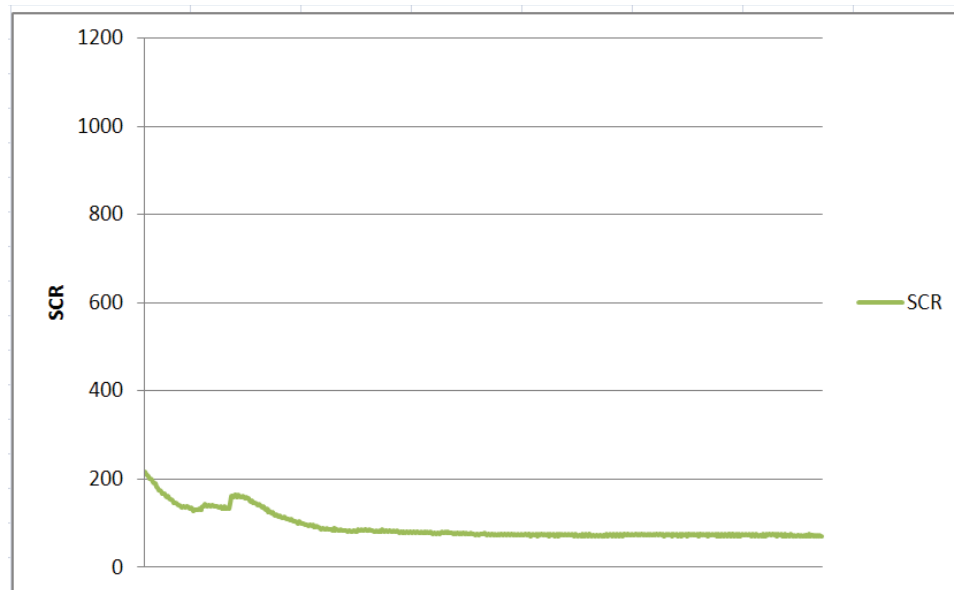


Figure 6.5: Skin conductance response of a subject in a relaxed state.

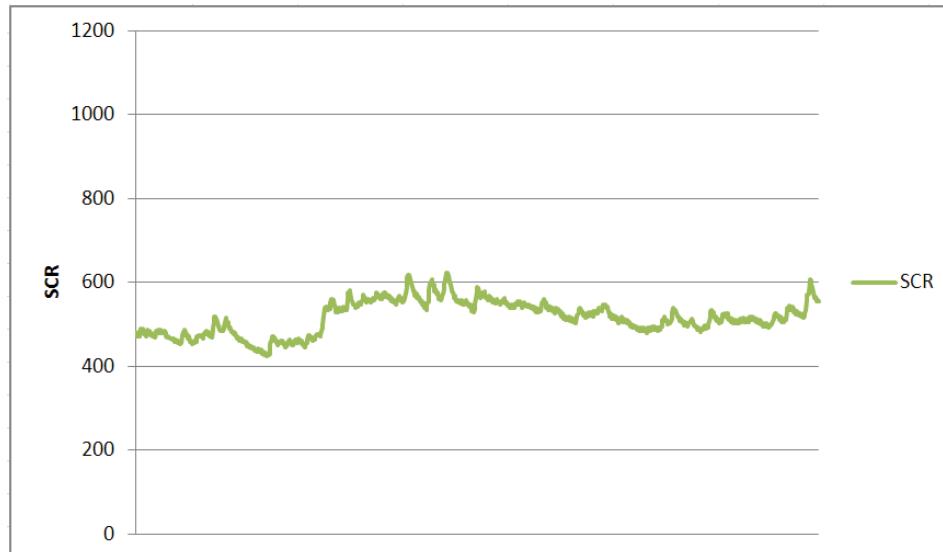


Figure 6.6: Skin conductance response of a subject in a happy (excited) state.

In the above figures we can visualize the difference between an individual who is in a relaxed state compared to one in an aroused state. The scales have been kept consistent throughout the project. Once the data was analysed, it proved that the SCR value had direct relationship with the level of arousal. The next step was to use the SCR signal for feature extraction in recognising human emotions. In this project, SCR is used for emotion recognition, therefore observing the change in these values is more important than the absolute values.

6.4 Skin Conductance Calculation

The signal from the skin conductance response (SCR) sensor is an analog value measured in millivolts (mV). As discussed earlier, the SCR does not have any specific unit or scale that has to be observed. Therefore in this project we use the raw voltage value from the sensor which is input into the microcontroller and processed by programming the microcontroller along with other analog signals. This is explained in the analog signal processing section 7.5.

7.0 Communication

7.1 Microcontroller (C8051F020)

In this project we use a C8051F020 microcontroller. The C8051F020 is a fully integrated mixed-signal system-on-a-chip microcontroller [96]. It has a total of 64 general purpose ports I/O (GPIO) pins. The lower ports (P0-P3) are both bit- and byte-addressable. The upper four ports (P4-P7) are only byte-addressable GPIO pins. The main features of the device are given below [96].

- High-Speed pipelined 8051-compatible CIP-51 microcontroller core
- In-system, full-speed, non-intrusive debug interface (on-chip)
- True 12-bit 100 ksps 8-channel ADC with PGA and analog multiplexer
- True 8-bit ADC 500 ksps 8-channel ADC with PGA and analog multiplexer
- Two 12-bit DACs with programmable update scheduling
- 64k bytes of in-system programmable FLASH memory
- 4352 (4096 + 256) bytes of on-chip RAM
- External data memory interface with 64k byte address space
- SPI, SMBus/I2C, and two UART serial interfaces implemented in hardware
- Five general purpose 16-bit timers
- Programmable counter/timer Array with five capture/compare modules
- On-chip watchdog timer, VDD Monitor, and temperature sensor

Apart from the above features, the C8051F020 has an on-board joint test action group (JTAG) debug circuitry which allows a non-intrusive, full speed, in-circuit debugging. This debug system supports inspection and modification of memory and registers. All analog and digital peripherals are fully functional while debugging using JTAG. Silicon Labs debug environment has superior configuration for developing and debugging embedded applications compared to standard microcontroller emulators, which use on-board ICE chips and target. The C8051F020 also comes with a development kit that provides all the hardware and software necessary to develop

application codes and perform in-circuit debugging. The development kit runs on windows based computer systems and can be connected to the microcontroller using an RS232-serial adaptor. Figure 7.1 shows the block diagram of C8051F020 microcontroller.

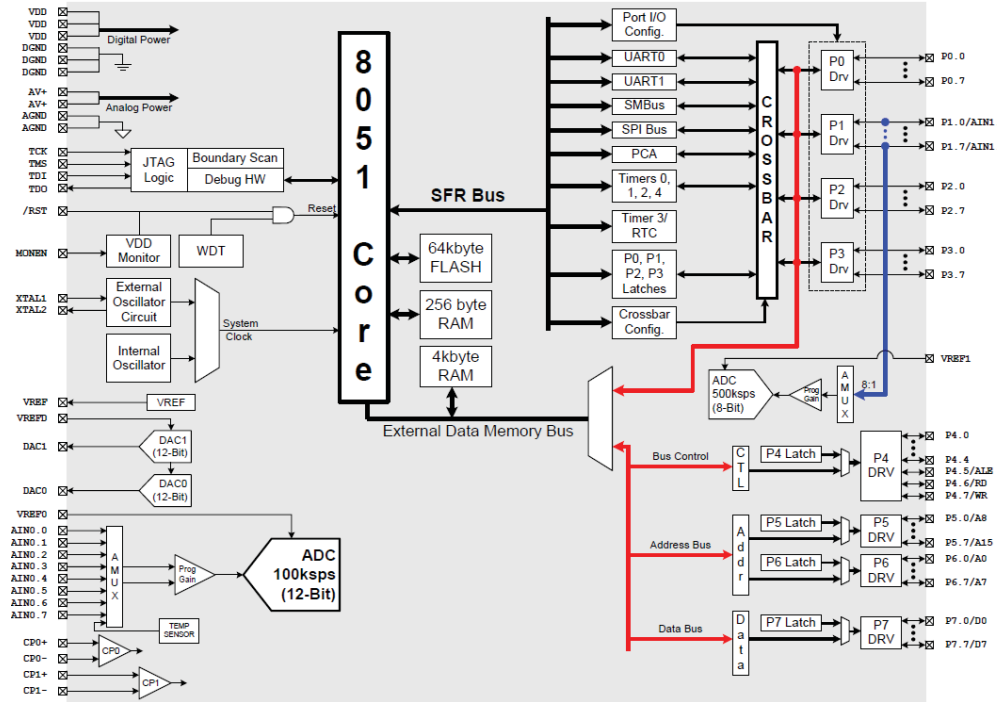


Figure 7.1: Block diagram of C8051F020 [96].

The reason for using C8051F020 in this project is its efficient circuit implementation, reduced board space, higher system reliability and low cost.

7.2 Serial Communication

In this project we use serial communication for data transmission. In serial communication, data is transmitted one bit at a time. There are two types of serial communication, asynchronous and synchronous. In asynchronous communication the transmitter and receiver do not share a common clock. The transmitter shifts data onto the serial line using its own clock and adds start, stop and parity check bits as shown in figure 7.2. In synchronous communication, blocks of data bytes are sent at a time over a serial line. In this project we use asynchronous transmission as it is used for low volume transmission which is the case in this project and it is easy to implement [97].



Figure 7.2: Asynchronous serial data format [97]

The C8051F020 MCU has an on-chip device called the UART which stands for universal asynchronous receiver/transmitters. The UART converts output data from parallel to serial and input data from serial to parallel [97]. The UARTs on a C8051F020 can operate in several modes over a wide range of frequencies. In our case we went for UART0 mode 1. Mode 1 provides standard asynchronous, full duplex communication using a total of 10 bits per data byte. One start bit, eight data bits (least significant bits first), and one stop bit [96]. Data is transmitted from the TX0 pin and received at the RX0 pin. On receive, the eight data bits are stored in SBUF0 (figure 6.3) and the stop bit goes into RB80 (SCON0.2).

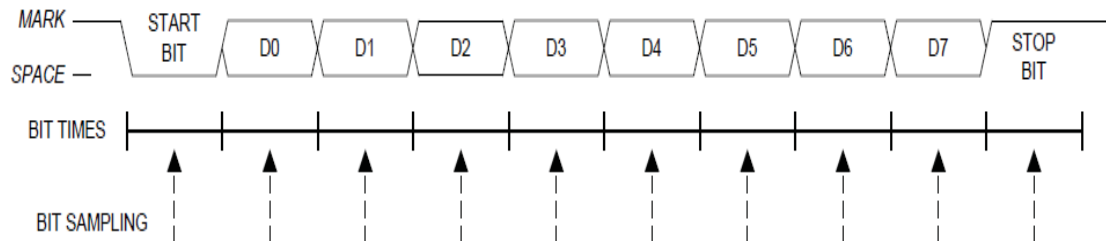


Figure 7.3: UART0 mode 1 timing diagram [97]

Data transmission begins when an instruction writes a data byte to the SBUF0 register. The TIO Transmit Interrupt Flag (SCON0.1) is set at the end of the transmission (the beginning of the stop-bit time). Data reception can begin any time after the REN0 Receive Enable bit (SCON0.4) is set to logic 1. After the stop bit is received, the data byte will be loaded into the SBUF0 receive register if the following conditions are met: RI0 must be logic 0, and if SM20 is logic 1, the stop bit must be logic 1. If these conditions are met, the eight bits of data are stored in SBUF0, the stop bit is stored in RB80 and the RI0 flag is set. If these conditions are not met, SBUF0 and RB80 will not be loaded and the RI0 flag will not be set. An interrupt will occur if enabled when either TIO or RI0 is set.

The baud rate generated in mode 1 is a function of timer overflow. UART0 can use Timer 1 operating in 8-Bit Auto-Reload Mode, or Timer 2 operating in Baud Rate Generator Mode to generate the baud rate. We use Timer 1 operating in 8-bit Auto-Reload mode. On each timer overflow event (a rollover from all ones - (0xFF for Timer 1- to zero) a clock is sent to the baud rate logic. Equation 5 shown below is used to generate the baud rate (9600bps) using Timer 1.

$$\text{Baud Rate} = \left(\frac{2^{SMOD0}}{32} \right) \times \frac{SYSCLK \times 12^{(T1M-1)}}{256 - TH1} \quad (5)$$

$$\text{Baud Rate} = 9600 \text{ bps}$$

where

SMOD0: Baud rate doubler disabled, 1

SYSCLK: 22.118400 MHz

TH1: 8-bit reload register for Timer 1, 112 (0x70)

T1M: Timer 1 clock select bit (CKCON), 1

7.3 ZigBee Wireless Communication

The communication between the monitoring system and the computer is achieved using ZigBee technology. ZigBee is a wireless technology developed as an open global standard to address the needs of low-cost, low-power wireless machine to machine (M2M) networks [98]. Table II shows a comparison between Wi-Fi, Bluetooth and ZigBee wireless technologies.

Table II: Wireless technology comparison chart [99]

Standard	Bandwidth	Power Consumption	Protocol Stack Size	Stronghold	Applications
Wi-Fi	Up to 54Mbps	400+mA TX, standby 20mA	100+KB	High data rate	Internet browsing, PC networking, file transfers
Bluetooth	1Mbps	40mA TX, standby 0.2mA	~100+KB	Interoperability, cable replacement	Wireless USB, handset, headset
ZigBee	250kbps	30mA TX,	4"32KB	Long battery life, low cost	Remote control, battery-operated products, sensors

In this project XBee Series 2 OEM RF modules which operate within the ZigBee protocol and uses 2.4 GHz frequency band, has been used. The main features of XBee series 2 RF modules are given below in table III.

Table III: Specifications of XBEE Series 2 [100]

Performance	
Indoor/Urban	Range up to 133 ft. (40 m)
Outdoor RF line-of-sight	Range up to 400 ft. (120 m)
Transmit Power Output	2mW (+3dBm)
RF Data Rate	250,000 bps
Serial Interface Data Rate	1200 - 230400 bps (non-standard baud rates also supported)
Power Requirements	
Supply Voltage	2.8 – 3.4 V
Operating Current (Transmit)	40mA (@ 3.3 V)
Operating Current (Receive)	40mA (@ 3.3 V)

Power-down Current	< 1 μ A @ 25oC
General	
Operating Frequency Band	ISM 2.4 GHz
Operating Temperature	-40 to 85° C (industrial)
Networking & Security	
Supported Network	Topologies Point-to-point, Point-to-multipoint, Peer-to-peer & Mesh
Number of Channels	16 Direct Sequence Channels
Addressing Options	PAN ID and Addresses, Cluster IDs and Endpoints (optional)

The pin configuration and assignment of XBEE series 2 RF modules are shown in figure 7.4.

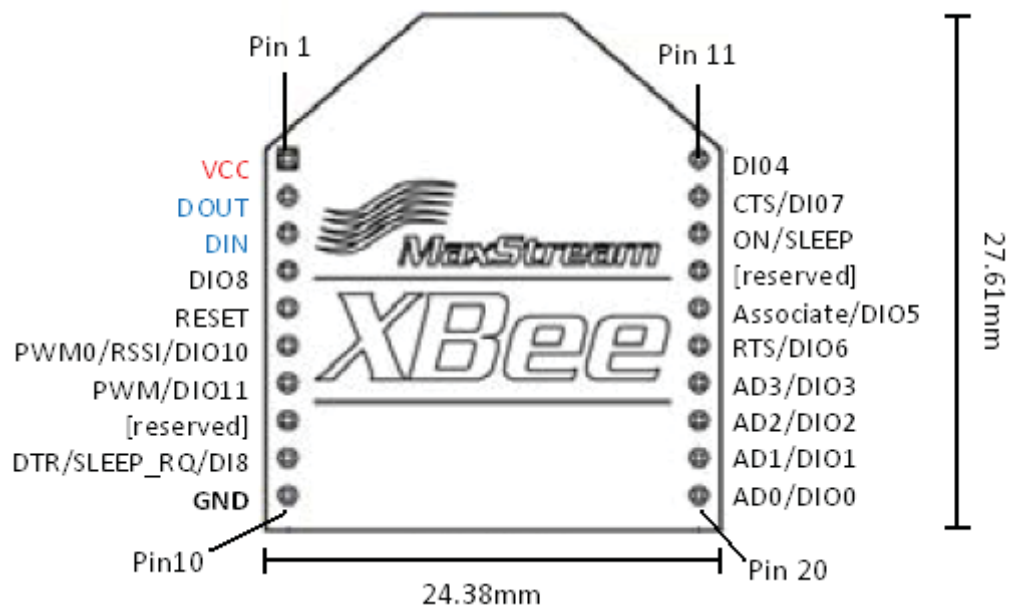


Figure 7.4: XBee series 2 module dimensions and pin assignment [99]

The VCC and GND pins of the module are connected to the 3.3V and ground pins of the microcontroller. The DIN and DOUT pins of the module are connected to digital port P0.0 (TX) and P0.1 (RX) of the C8051F020 microcontroller respectively. The other pins are not used in this project. Once connected, the XBee modules

require configuration. This can be done using software called X-CTU which is provided with the XBee RF modules or it can be downloaded for free from Digi International website. The details of XBee configuration are explained in the XBee modules configuration section below.

7.4 X-CTU XBee Modules Configuration

X-CTU is used for configuring XBEE series 2 modules in this project. It is designed to interact with the firmware files found on Digi's RF products and to provide a simple-to-use graphical user interface [101]. X-CTU functions with all windows-based computers. Once the X-CTU program is launched it comes up with the front panel as shown in figure 7.5 with PC settings tab selected by default.

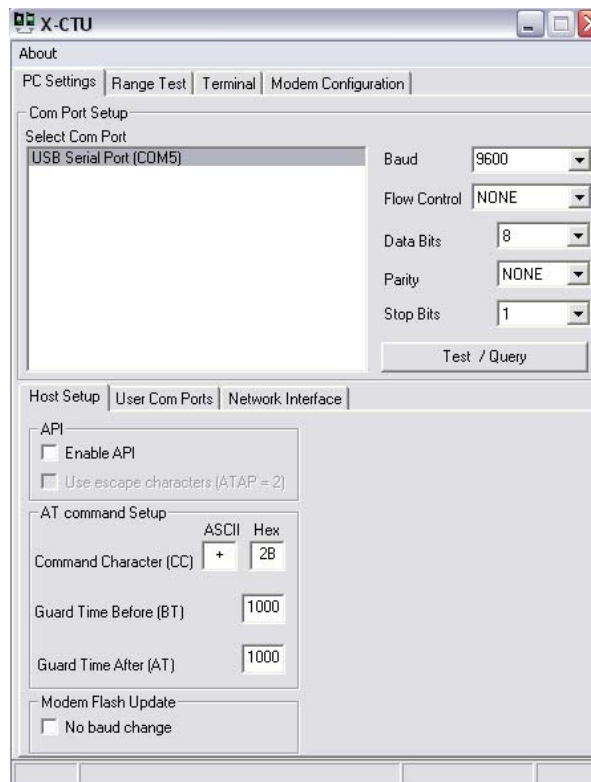


Figure 7.5: Front panel of X-CTU software.

The details of each tab are explained in detail below.

PC Settings: The PC settings tab allows the user to select a COM port and configure the selected COM port settings when accessing the port. These settings include baud rate (both standard and non-standard), flow control (hardware, software, none),

data bits (4, 5, 6, 7, and 8 data bits), parity (None, Odd, Even, Mark and space) and stop bit (1, 1.5, and 2). In our case the baud rate was set to 9600, flow control to none and 8-None-1 for data bits, parity and stop bits settings. Once these settings are configured the next step is to test these settings which are done by pressing the Test/Query button. If the settings are correct, a response message will appear as shown in figure 7.6.

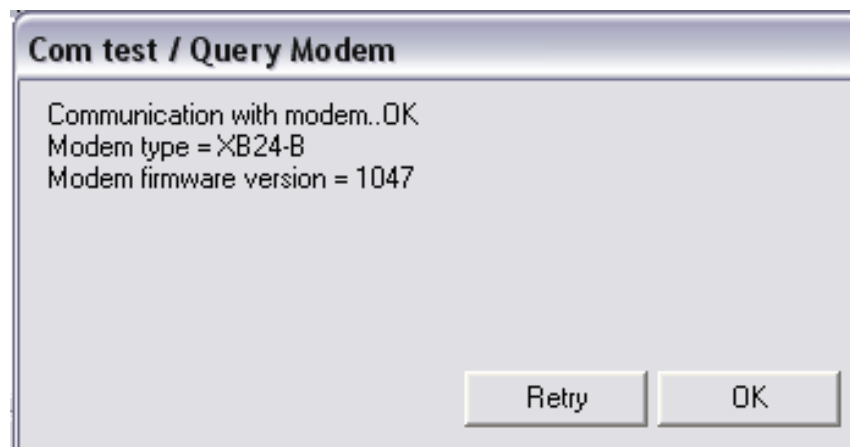


Figure 7.6: Response message of a successful Com test.

Modem Configuration: Once the Com test results are successful, the next step is to configure the modem. This is done by clicking on the modem configuration tab. The modem configuration tab allows the user to program the modules firmware settings via a graphical user interface. This tab also allows users to change/update firmware versions. In order to program the modules, the first step is to read the modem by clicking on the read button. Once the module's firmware has been read, all the information about the module is displayed e.g. modem type, function set, firmware version, networking, addressing etc. In our case one of the modules is set to ZNET 2.5 coordinator and the other is set to ZNET 2.5 router/end device as shown in figure 7.7. They both share the same PAN ID and the baud rate is set to 9600bps for both the modules. Once these settings had been done, they were then uploaded onto the module's non-volatile memory by pressing the write button. While writing to the modules, the "always update firmware" option is also selected in order to make sure that the firmware is up to date.

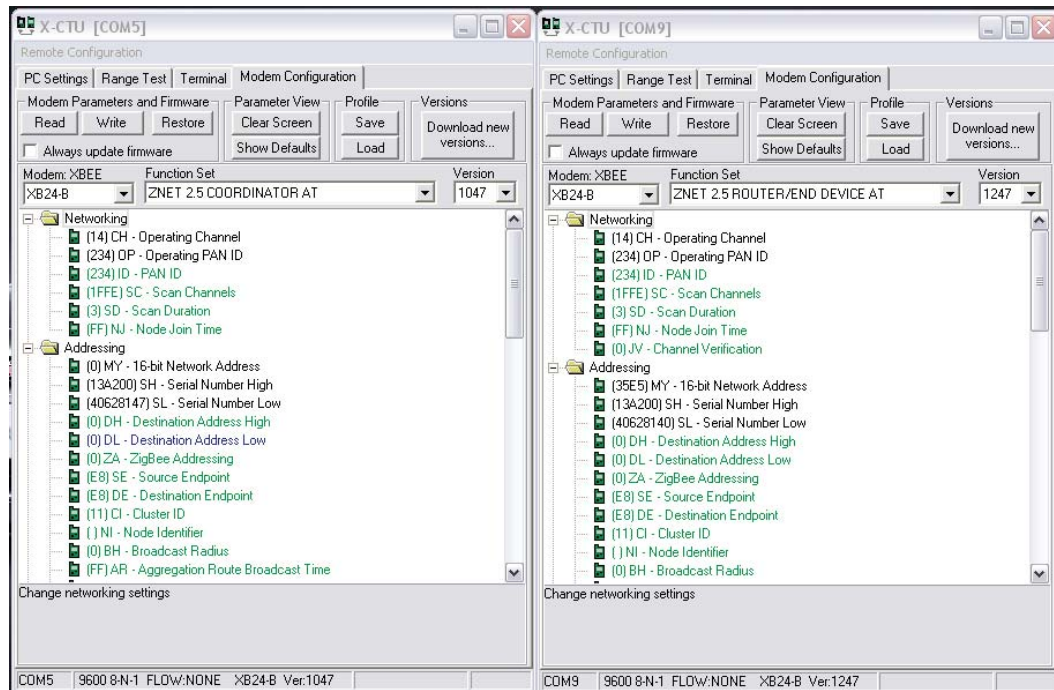


Figure 7.7: XBee module configuration menu for coordinator (left) and router (right).

Terminal: The terminal tab allows users to access computers COM port with a terminal emulation program. This tab also allows the ability to access the modules' firmware using AT commands. Once both the router and coordinator modules were configured, they were tested by sending a message from the router module to the coordinator module as shown in figure 7.8.

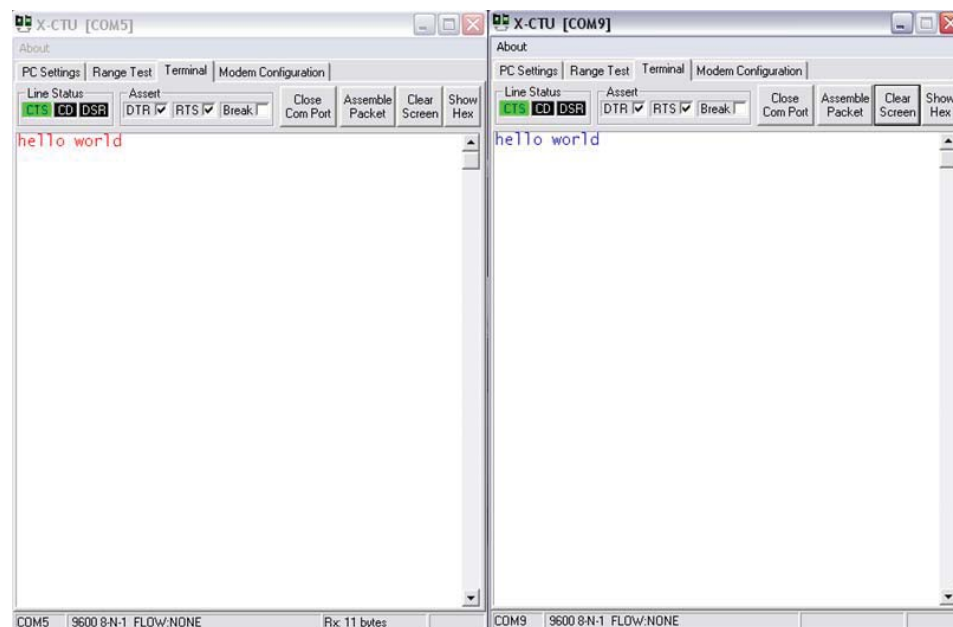


Figure 7.8: Coordinator (left) and router (right) terminal windows.

Range Test: Range test tab allows users to perform a range of tests between two modules. This part of the software wasn't used in this project.

Once the modules were configured, they proved that they were able to communicate with each other. The next step was to integrate them into the system for wireless communication. The XBee router/end device module was placed on front of the box (system) for better signal with an ON/OFF switch. As the system is capable of communicating wirelessly as well as using USB, the switch was used in order to save power by turning it off if the data transfer was through USB. Figure 7.9 shows the XBee router/end device located at the front of the system.



Figure 7.9: XBee router/end device transmitting data.

The coordinator on the other hand is plugged into the computer using XBee explorer USB. Figure 7.10 shows the XBee coordinator receiving data from the XBee router/end device.

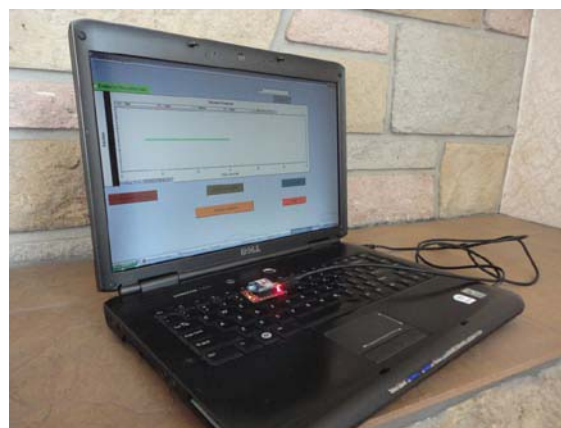


Figure 7.10: XBee coordinator receiving data

7.5 Analogue Signal Processing

Analog signals from the temperature and SCR sensors are input into the ADC0 of the microcontroller. ADC0 consists of 9-channel configurable analog multiplexer (AMUX0), a programmable gain amplifier (PGA0) and a 12-bit Successive Approximation Register (SAR) ADC [97]. Three out of eight of the AMUX0 channels are used for measuring skin temperature, room temperature and skin conductance. Timer 3 is configured to auto-reload at specified intervals using SAR clock of 2.5 MHz as its time base. The ADC makes repeated measurements at a rate of 50 KHz determined by SAMPLE_RATE using Timer 3. The end of each ADC conversion, initiates an interrupt which calls an averaging function. Once the ADC0 completes a conversion, the ADC0 ISR routine is called. Each value is added to a running total <accumulator>, and the local decimation counter < INT_DEC > is decremented. When < INT_DEC > reaches zero, the decimated result is posted in the global variable <Result []>. <INT_DEC> samples are averaged and the Result values are updated. The measured voltage is given by (6):

$$ADC0_{out} (mV) = Result[i] (bits) * \frac{Vref(mV)}{4095(bits)} \quad (6)$$

where

$Vref$: 2430mV

In the above equation, [i] represents analog inputs from 0-7. In this project AIN0.1 was used for skin temperature, AIN0.6 for room temperature, and AIN0.7 for skin conductance. The conversion of voltage value into temperature and skin conductance values are explained in the sensor sections (5.4, 6.4). The detailed code of the ADC0 is available in the appendices section 13.0.

7.6 Graphical User Interface (GUI)

In order to monitor, store and analyse the data coming from the system, we had to design software that would carry out these functions in a user friendly way. In the beginning we used LabView for data monitoring and storing. Data from the

sensors were transmitted wirelessly using XBee and displayed using LabView. Figure 7.11 below shows the front panel of the designed interface using LabView.



Figure 7.11: Front panel of LabView.

In the figure given above, the graphical displays show the three raw signals (left) and their first and second derivatives (right). The top two graphs display BPM signal (left) and its first and second derivatives (right). The middle two display the skin temperature signal (left) and its first and second derivatives (right). The bottom two graphs are for skin conductance response signal (left) and its first and second derivatives (right). All these graphs are plotted in real time hence the actual time is displayed on the x-axis. On the top left of the screen is the path to the file where all the data will be stored. A save button next to the file path gives the option to store the monitored data. Below the file path is the panel for serial communication. The first drop down box is for COM port selection which depends on the port to which the XBee coordinator is connected. The next drop down box is for the baud rate which is 9600 bps for this project. The other settings are set to default which includes the data bits set to 8, parity set none and stop bits set to 1. These settings have also been configured into XBee modules which have been explained in the X-CTU configuration section 7.4. LabView was only used in initial stages of data monitoring and storing and its use was discarded as LabView does not produce executable programs. For this reason we decided to design a GUI using Visual Studio

C# which will be capable of data monitoring, storing and emotion evaluation. Figure 7.12 below shows the front panel of the GUI designed using Visual Studio C#.

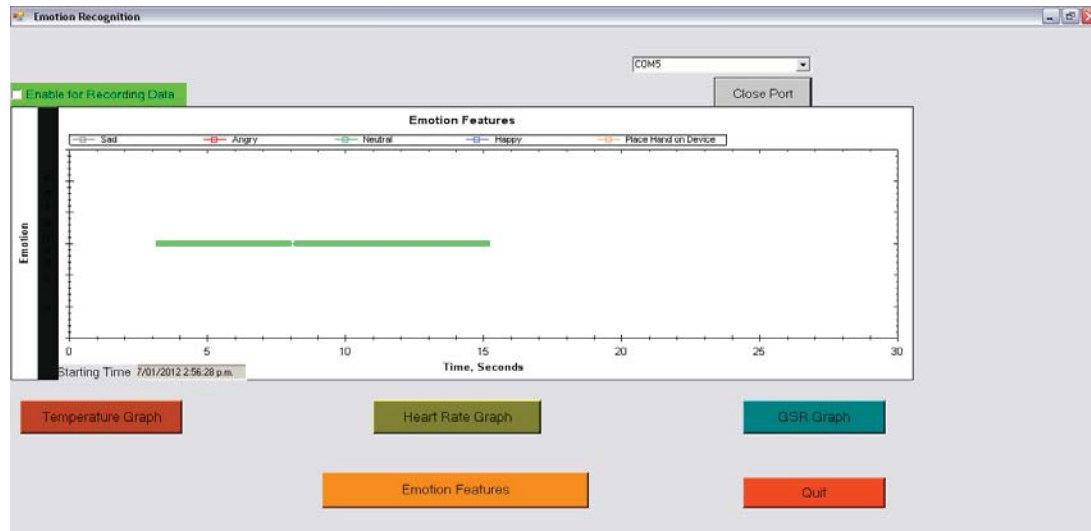


Figure 7.12: Front panel of the designed software.

A simple front panel was designed with a graph displaying an emotion at a particular instance. Each emotion is displayed by a coloured line. Happy emotion is represented by a blue line, neutral state by light aqua, angry state by red and sad state by grey. In case the hand is not placed on the system, an orange line will appear which means that there is no hand to take data from or to place a hand for data monitoring. Figure 7.13 below shows a collective representation of all four emotions displayed on the front panel of the GUI.

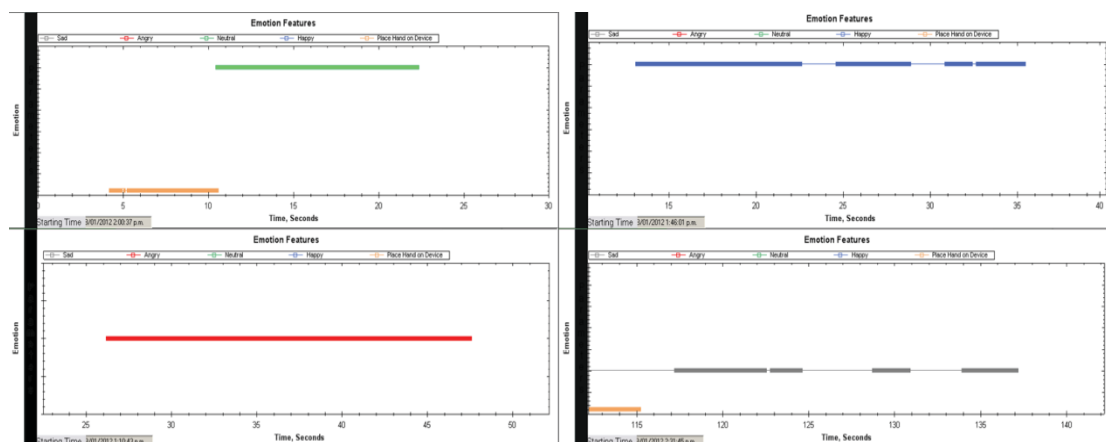


Figure 7.13: Graphical display of all four emotions.

The front panel has a drop down box for COM port selection and a data recording select option for storing data as text file for later use. Unlike LabView's

front panel, the graphs for the sensor signals are accessed only by pressing the graph buttons i.e. heart rate graph, temperature graph and SCR graph. Figure 7.14 below shows the graphs displaying real time signals from the sensor.

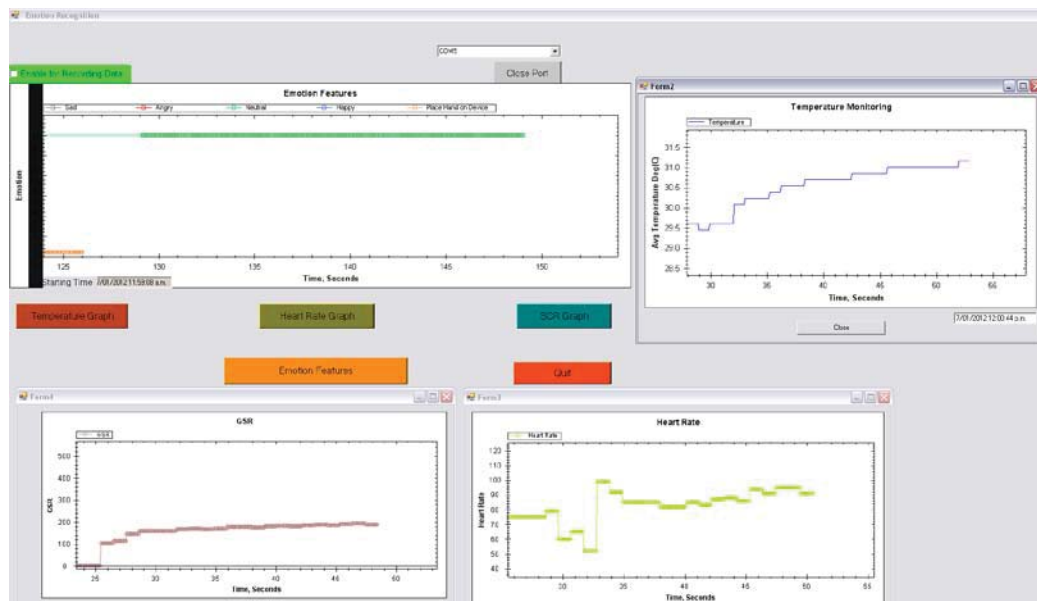


Figure 7.14: Sensor signal graph along with the non-graphical real-time data

These graphs show the real time signal for the three sensors for a particular time period. The amplitude of the signals is displayed on y-axis while the x-axis shows the time in seconds along with the starting time in text box. Figure 7.15 below shows the front panel along with a non-graphical window showing real-time data.

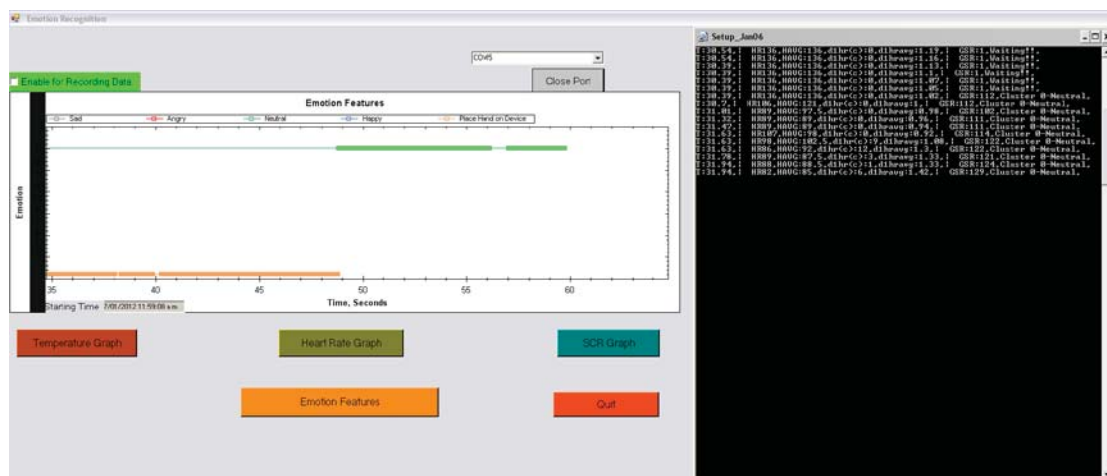


Figure 7.15: Front panel along with non-graphical window displaying real time data.

The analysis and evaluation of emotions based on real time data is explained in the results and discussion section below.

8.0 Results and Discussion

The aim of this project is to develop a system that is capable of evaluating human emotions based on information provided by physiological sensors. As discussed in the literature review section, emotions play a vital role in decision making, problem solving and communicating. Emotions do not arise through free will and are often accompanied by physiological changes. Therefore it is important to monitor these changes as they contain information that can help in improving human wellbeing.

In this project, we monitor physiological signals including heart rate, skin conductance response and skin temperature. Based on the output of these signals we evaluate four basic emotions i.e. happy, sad, angry and neutral. The sensors were tested thoroughly for data reliability, accuracy and ease of use, before they were used for emotion evaluation. Once the sensors' output and the casing design were satisfactorily arrived at, the next step was to monitor individuals in their four emotional states. Figure 8.1 shows the final design of a system along with the 3D model designed in SolidWorks.

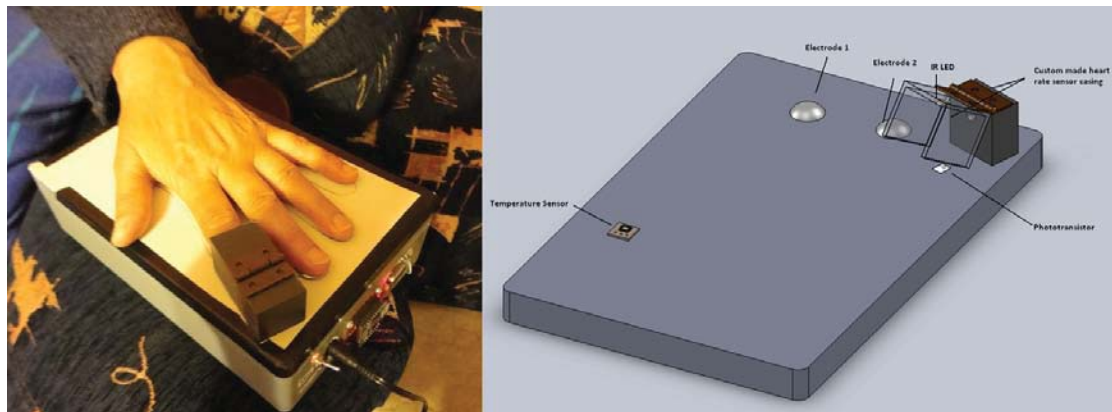


Figure 8.1: Final design of the actual system (left) and 3D model (right).

In order to obtain emotions, initially it was decided to capture data from subjects in natural environments. This was not easily achievable and feasible as it required monitoring the subjects for long hours and then linking the data back to the actual events. It was then decided to design an experiment using movies and TV shows for happy and sad emotions, arguments for angry emotions and resting while sitting for

neutral state. Fourteen subjects were chosen to take part in this experiment with ages ranging from 19-72 years. The subjects were monitored independently. Verbal consent was obtained from all the participants before the data was collected. To begin with, the system was connected to the subject and a few test runs were conducted, before storing the data for data training. The idea of the test runs was to make the subject feel comfortable with the system. It also ensured that the signal was reliable and consistent for each individual. Once the test runs were completed, the comedy show was turned on and data monitoring was initiated and stored. After the show was over the subject was asked to relax while sitting on a couch. The data was monitored again after a break of 30mins and saved for 5-7mins. Figure 8.2 shows data monitoring of an elderly while watching television.



Figure 8.2: Data monitoring of an elderly while watching television.

Similarly, to obtain sad emotions, a sad emotional movie was put on and the subject was monitored. The data was monitored and saved during sad emotional scenes. To generate angry emotions, debates on religion, race, culture and politics were initiated. The subject was monitored and the data was saved during the most intense state of the argument and 5 minutes following the argument. The latter part was to observe the process of coming back to a neutral state after the argument had concluded. These experiments were carried out for 7 male and 7 female subjects

with a consistent experimental setup. The following figures show the monitored data for subjects in the four emotional states from the three physiological sensors.

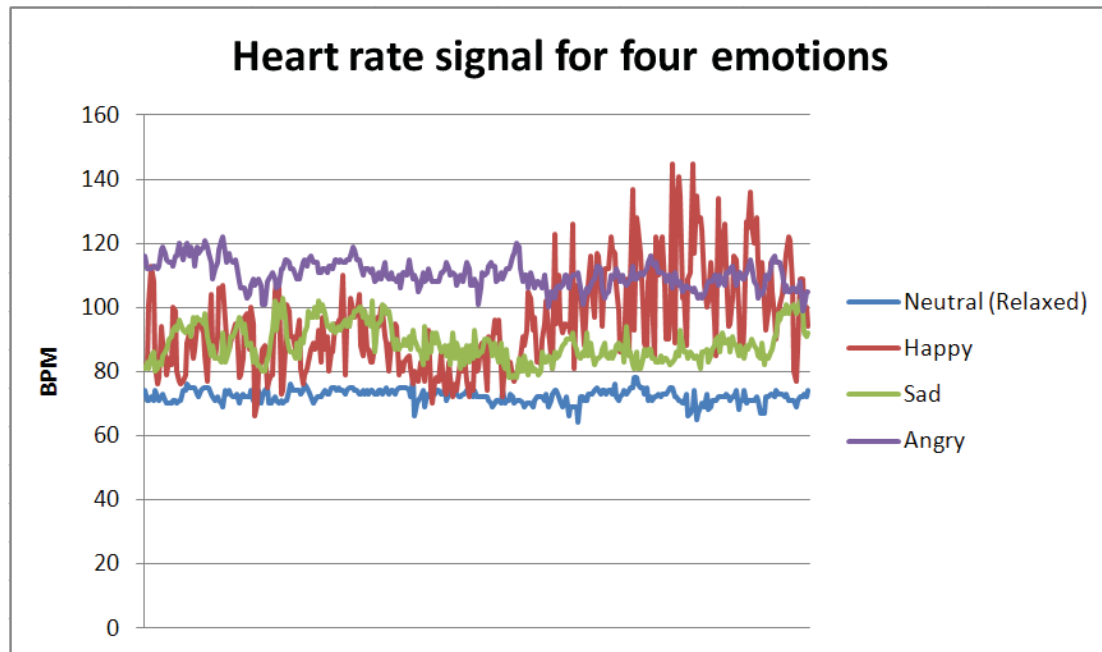


Figure 8.3: Heart rate observed for subjects in happy (excited), sad, neutral and angry states.

From the graph above heart rate variation can be easily visualized. It helps in recognizing the difference between the different emotional states, at a glance. Angry state has a higher value in comparison to neutral. Sad and happy emotions tend to fluctuate at a higher rate in comparison to angry or neutral. In order to gain more information about the fluctuations, the software was programmed to calculate the rate of change by obtaining first and second derivatives. Figure 8.4 below shows the first derivative test for the emotions.

The first derivative tests below, show visual changes between the data for the four types of emotions. These outputs make the differences between the emotional states and its variations within each emotion more obvious. The absolute values of the first derivatives data is used later for data clustering. The second derivative tests are not shown here but were also utilized for data clustering.

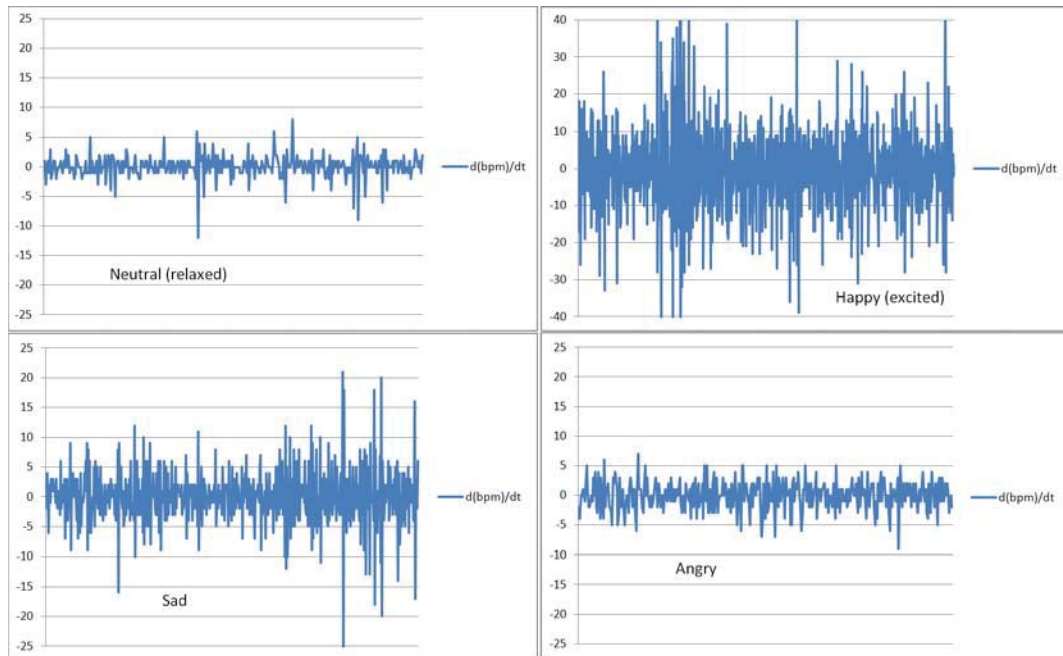


Figure 8.4: First derivative test of heart rate signal observed for subjects in neutral (relaxed), happy (excited), sad, and angry states.

The next physiological sensor i.e. skin conductance response (SCR) for the four emotions was also observed as given in Figure 8.5 below.

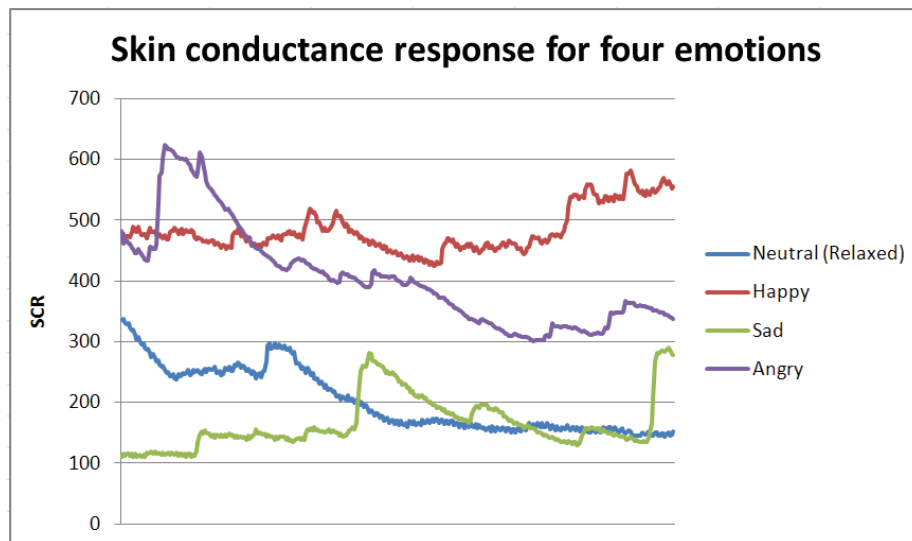


Figure 8.5: Skin conductance response (SCR) of subjects in neutral, happy (excited), sad and angry states.

From the above graph a major difference in SCR values can be seen for different emotional states with angry state showing the highest values while sad state shows

the lowest values. These values were expected from the literature review which showed that the SCR values are directly related to level of arousal which has already been explained in the skin conductance section. The skin temperatures of the subjects along with the room temperature were also monitored which is shown in Figure 8.6.

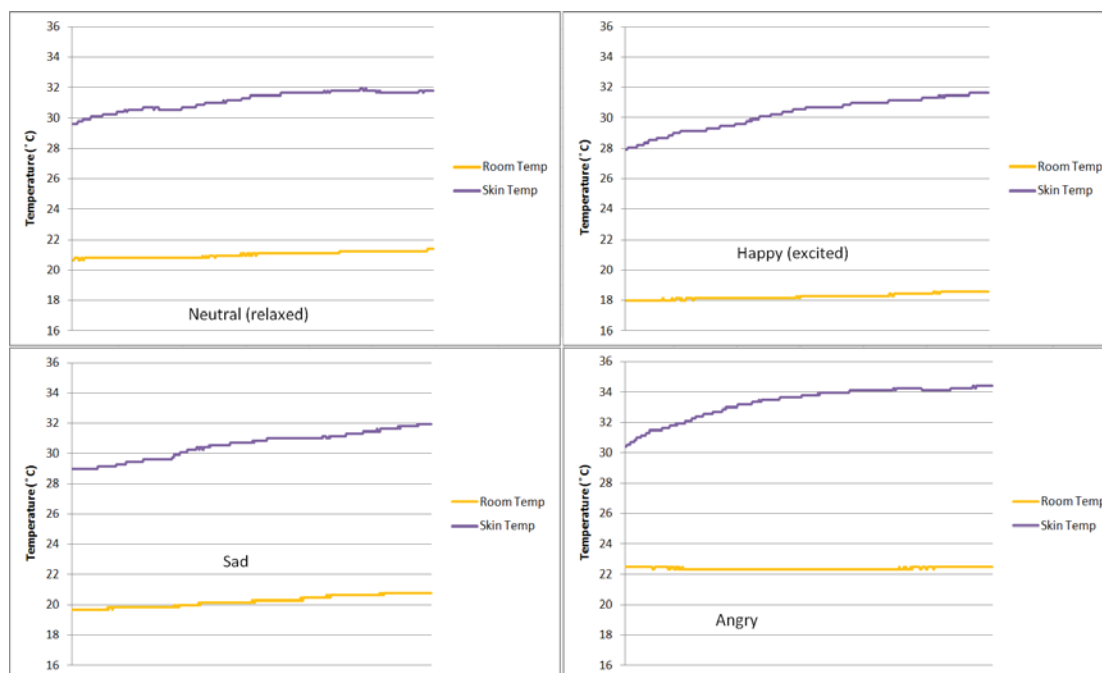


Figure 8.6: Skin temperature observed for subjects in neutral, happy (excited), sad and angry states.

As the skin temperature is affected by room temperature it was necessary to take it into consideration in this project. The skin temperature monitored for the subjects did not show significant change between the four states. However, the highest temperature was observed for the angry state that was comparable to other states. The relationship between skin temperature and emotions has already been studied by many researchers. Ekman *et al.* [102] in their study found that the skin temperature of fingers was higher in angry state when compared to other states, which was reconfirmed by our analysis.

The above results showed that emotions do have effect on the physiological signals which can be visualized by continuous monitoring. The heart rate variability and skin conductance response showed significant results across all four emotions. The temperature signal on the other hand showed significant change for angry state as

compared to other states. From this point, it was decided to cluster the data into groups of four (four emotions). Data clustering is a data exploration technique that allows objects with similar characteristics to be grouped together in order to facilitate further processing [103]. Data clustering has many engineering applications. In this project k-means algorithm was applied which is a popular data clustering technique. K-means clustering is a method of cluster analysis which aims to partition 'n' observations into 'k' clusters in which each observation belongs to the cluster with the nearest mean [104]. The main idea of k-means clustering technique is to find the centres or centroids of natural clusters in the data using iterative refinement technique. For a given a set of observations (x_1, x_2, \dots, x_n) , where each observation is a d-dimensional real vector, k-means clustering aims to partition the 'n' observations into 'k' sets ($k \leq n$), so as to minimize the within-cluster sum of squares (WCSS) which is given by:

$$J = \sum_{j=1}^k \sum_{i=1}^n \| x_i^{(j)} - c_j \|^2 \quad (7)$$

where,

$\| x_i^{(j)} - c_j \|^2$, is the distance measure between a data point $(x_i^{(j)})$ and the cluster centre (c_j) [105].

Based on our data and the number of emotions to be recognized, it was decided to create four clusters using k-means clustering technique. For this purpose we used 'WEKA 3' which is open source software used for data pre-processing, classification, regression, clustering, and visualization [106]. In order to cluster the data, the training data collected from 14 individuals was used. This data was pre-processed before clusters could be formed. Once the pre-processing was complete, the next step was to choose the clustering technique, which in this case was k-means clustering. Along with k-means clustering technique, there were a few options that

had to be selected before clustering began. These included the function distance and the number of clusters. For this study Euclidean distance was chosen as the distance function. Euclidean distance is the most usual, natural and intuitive way of computing a distance between two samples. It takes into account the difference between two samples directly, which is based on the magnitude of changes in the sample levels. This distance type is usually used for data sets that are suitably normalized or without any special distribution problem [107]. The application of Euclidean distance is not limited to economics, statistics, political science, and decision theory but it is also used for DNA sequencing, cryptography and image recognition [108]. Therefore, for distance function we chose Euclidean distance in 'WEKA' in order to form 4 clusters as shown in figure 8.7.

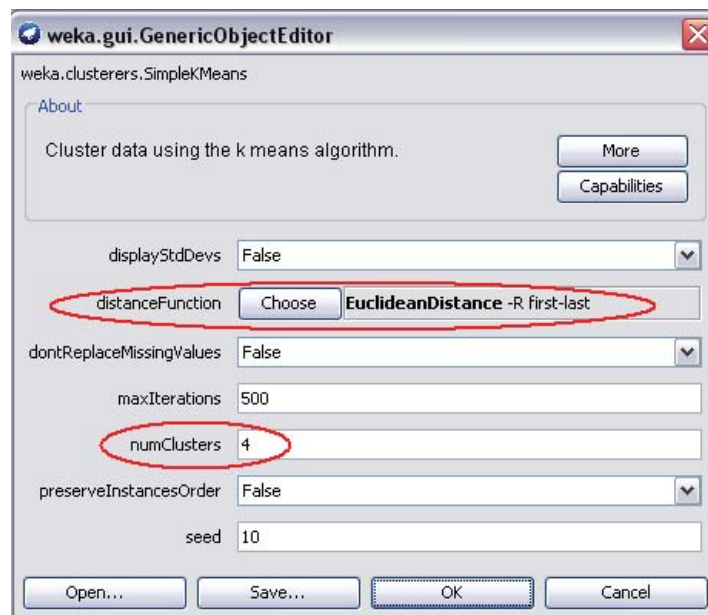


Figure 8.7: K-means options window.

Once all the settings were complete, the next step was to initiate clustering in 'WEKA'. After the clustering is complete, WEKA displays the details of the attributes, the time taken to form clusters and the significance of each attribute to a particular cluster as shown in Figure 8.8.

```

kMeans
=====

Cluster centroids:

Attribute      Full Data      Cluster#
                (3468)      0          1          2          3
                (1358) (387)    (745)    (978)
=====
Stemp          29.1603      31.7129    33.3274    26.5245    25.9747
d1stemp        0.0044        0.0054     0.0104     0.005      0.0003
d2stemp        0.0001        0.0002      0          0          0.0002
bpm            84.2388      81.5037    110.1757    63.9933    93.1953
d1bpm          -0.058       0.0331     0.0052     0.0054     -0.2577
d2bpm          0.3085       0.1097     0.1034     0.3772     0.6135
avgbpm         84.2677      81.4871    110.1731    63.9906    93.3241
scr            302.5582     201.7857    391.7313    159.3517    516.2883
d1scr          -0.2076      -0.2467    -0.5116    -0.3329     0.0624
d2scr          0.0055       0.0891     -0.2997     0.0067     0.0092
absd1bpm       3.8642       2.0817     1.9121     3.1007     7.6933

Time taken to build model (full training data) : 0.24 seconds

=== Model and evaluation on training set ===

Clustered Instances

0      1358 ( 39%)
1       387 ( 11%)
2       745 ( 21%)
3       978 ( 28%)

```

Figure 8.8: Attribute details using k-means.

From the above attribute chart one can see that based on 11 variables 4 clusters have been formed. The 11 variables used for data clustering include skin temperature (Stemp), first derivative of skin temperature (d1stemp) and second derivative of skin temperature (d2stemp), heart rate (bpm), first derivative of heart rate (d1bpm) and second derivative of heart rate (d2bpm), average of heart rate (avgbpm), skin conductance response (SCR), first derivative of skin conductance response (d1scr), second derivative of skin conductance response (d2scr) and finally absolute value of the first derivative of the heart rate signal. From the above attribute details provided by WEKA, we can see the effect of attributes on a particular cluster. However, the attributes marked by red circles are more significant and are therefore considered for software development. These are skin temperature (Stemp), heart rate (bpm), first derivative of heart rate (d1bpm), skin conductance response (SCR) and absolute value of the first derivative of heart rate. The others

have minor significance as compared to these five attributes. The visual representation of the clusters formed is shown in figure 8.9.

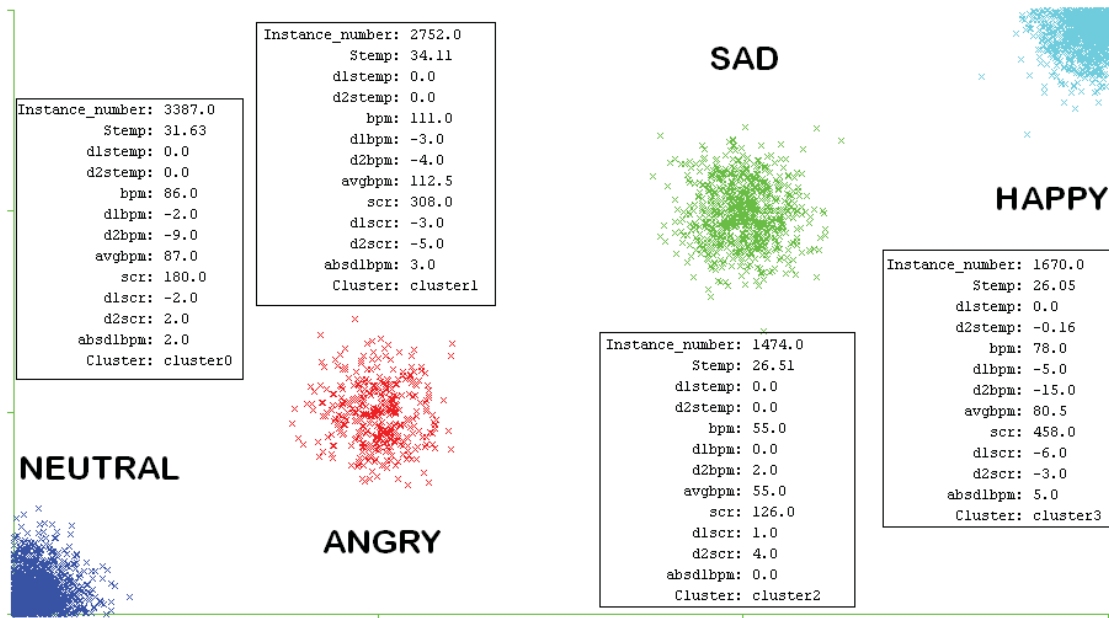


Figure 8.9: Cluster formation using k-means algorithm.

The above clusters are formed based on the combined details of all 11 attributes. Figures 8.10 to 8.13 below show the relationship between a cluster and a particular attribute.

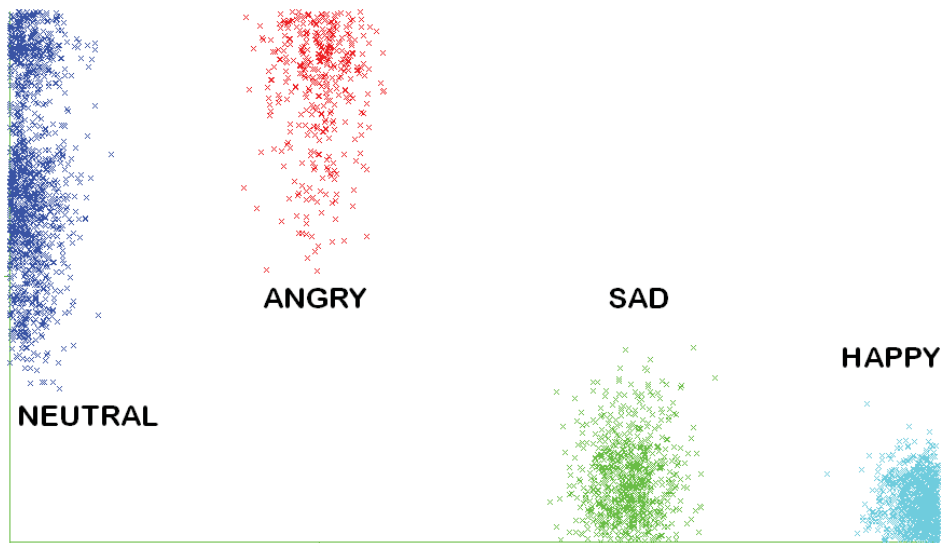


Figure 8.10: Cluster formation for skin temperature data.

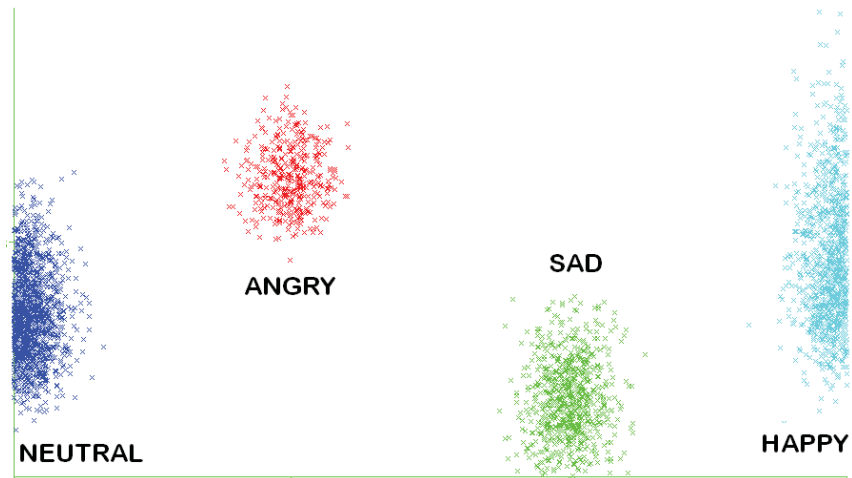


Figure 8.11: Cluster formation for BPM data.



Figure 8.12: Cluster formation for first derivative of BPM data.

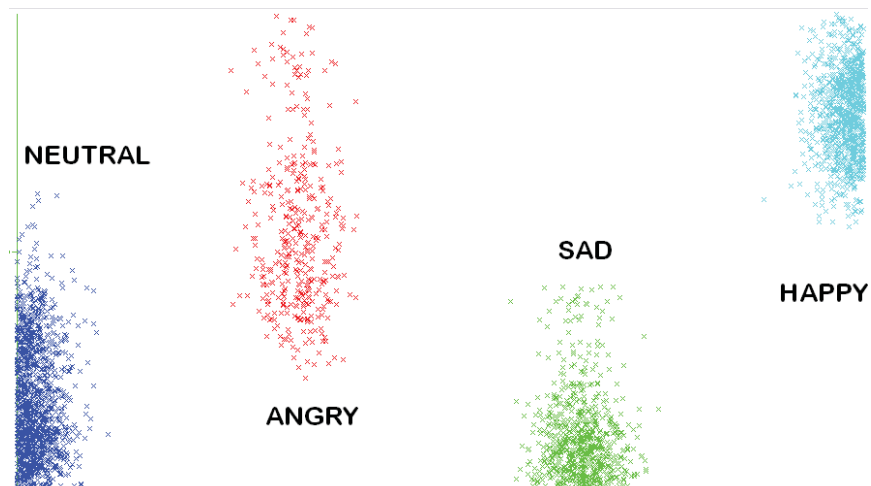


Figure 8.13: Cluster formation for skin conductance response data.

The above figures give a visual presentation of clustered data using k-means clustering technique. In figure 8.10, we can see that data points for skin temperature have the highest values for angry state and neutral states. These data points are less spread out for angry state with the centroid being towards the higher value as compared to neutral state. In Figure 8.11, the clusters formed for BPM data show that the angry state has data points with higher heart rate values. For happy state, the data points are widely spread compared to other states. In order to get more information out of the BPM data, we have to look into the first derivative test of the BPM data. Figure 8.12 shows that the first derivative BPM values are very close to the centroid for neutral, angry and sad emotions. For happy state the data points are widely spread due to a larger rate of change. Similarly, figure 8.13 depicts the clusters formed for SCR data with high values of SCR for happy and angry states while low SCR for neutral and sad states. This was true as research show that the SCR values are directly related to the arousal level of a person, therefore in angry and happy states we expect to see high SCR values while in sad and neutral state we expected a lower SCR.

The clusters formed using k-means clustering algorithm matches with the results obtained from individual emotion monitoring and data visualisation. Based on the above information and conditions, the software was developed and is capable of differentiating between four different emotional states. The details of the software are explained in the GUI section.

After the software was fully designed and developed, the next step was to monitor individual's emotional states. The 20 individuals monitored in both natural and designed environments were able to achieve a recognition rate of 86.25% and their individual emotion scores are given in Table IV below.

Table IV: Emotion recognition rate of the developed system.

Expected Emotion	Observed Emotion				% Correct
	Happy	Neutral	Sad	Angry	
Happy	17	3	0	0	85%
Neutral	0	20	0	0	100%
Sad	0	6	14	0	70%
Angry	2	0	0	18	90%

From the above results we can see that the neutral state achieved 100% results compared to other states. The neutral state was the reference state for other emotions and was easily recognised by the developed system. For happy state, a recognition rate of 85% was observed. During the happy state monitoring, some individuals showed emotions of excitement to a higher extent or level compared to others. Therefore in a few instances (15%) neutral state was observed instead of the happy state. For sad emotions the lowest recognition rate of 70% was achieved. As seen from earlier data visualization and clustering, the difference between sad state and neutral state was minimal in terms of all three signals. Therefore we did expect to get mixed results between sad and neutral state. Similarly for the angry state we achieved a recognition rate of 90%. This was because both happy and angry states are high arousal states, with high heart rate. The only visual data difference between happy and angry states was the skin temperature. Since the skin temperature is largely affected by room temperature, happy states for two individuals was observed who in reality were in an angry state (their skin temperature was low due to lower room temperature). Overall the recognition rate was found to be 86.25%.

8.1 Key findings and observations

As discussed earlier in this thesis we have monitored healthy individuals up to 72 years of age. While analysing the collected data from healthy elderly individuals we observed that the heart rate and SCR values were lower and more consistent as

compared to younger adults. This analysis showed that healthy old people tend to relax easily compared to young individuals. These readings were consistent throughout data collection over various instances. Similarly, during data analysis and visualization we found that not everyone's physiologically recognised emotions were of the same level or extent. Some people show less variability in their data output compared to others in presence of external stimuli.

During data collection, two subjects were observed to have very high SCR values as well as slightly higher heart rate under normal conditions as compared to other subjects. Further studies and discussions revealed that both the subjects were asthmatic. Asthma is an inflammatory disease of the airways of lungs, leading to wheezing, shortness of breath, chest tightness, and coughing [109]. Literature review has shown that stress symptoms and asthma are related and could cause changes in the heart rate and breathing patterns [110]. If the stress levels are severe, they can cause anxiety and panic attacks. Asthmatic patients are said to be vigilant and extra cautious as they constantly anticipate the next asthma attack. Their hyper vigilant attitude makes them over concerned even on slight physical or mental disturbances. Therefore when asthma symptoms occur they affect a person's emotional state. Also, medications used for controlling asthma have side effects including the triggering of anger in asthmatic patients. These studies proved helpful in finding the cause of high SCR and heart rate in asthmatic people. It also shows that this system can help in identifying other health problems due to abnormal output from the signals.

During data monitoring, an opportunity arose to monitor subjects who were fasting (Islamic fasting). During fasting the subjects are forbidden from eating and drinking any sorts of foods and drinks including water [111]. While monitoring these subjects, a comparatively low heart rate as well as low skin conductance response due to lower energy levels was observed. Therefore it was important to monitor subjects with normal energy levels for reliable physiological information regarding emotions. On the other hand, an increased heart rate level in subjects due to caffeine intake was observed. According to research caffeine stimulates the central

nervous system by blocking adenosine. Adenosine is a neurotransmitter that causes a calming effect in the body. The blocking of adenosine causes the adrenal glands to release adrenaline, also known as the fight or flight hormone. This causes an increase in heart rate, tightened up muscles and release of glucose into the blood stream [112]. Also, caffeine has a half life of 6 hours which means that the effect of caffeine stays in body even after 6 hours of intake. In our experimental design the subjects were asked to avoid caffeinated drinks 6 hours prior to the experiments.

We also observed electromagnetic interference in ZigBee wireless communication due to mobile phone signal within range. In order to avoid this, the subjects were asked to switch off mobile phones before data collection. The above observations helped in finding the cause to various problems and matters of concern which in turn helped in improving the system.

9.0 Conclusion

In this project we have developed a real time emotion recognition system, based on data provided by physiological sensors. The literature review enabled an appropriate method of selection for the sensors utilized in order to achieve emotion recognition. Physiological sensors were found to be the best approach to recognize emotional changes, as they provided information about changes that take place physiologically and are out of a person's control. Information and knowledge gained from other researches helped in providing information about the ranges of the physiological parameters and allowed in confirming results obtained from this study.

The heart rate sensor used in this project has been designed in lab with the capability of monitoring real time heart rate and obtaining reliable data output. The skin temperature sensor used in this project measures the skin temperature from the palm area with ease and has accuracy of $\pm 0.5^{\circ}\text{C}$. The output of the designed skin conductance response sensor has shown a direct relationship with the level of arousal. The sensors have been integrated and placed on a surface of a designed box, slightly larger than an average human hand, for collecting data from the left hand. This design enabled an easy and comfortable data monitoring system.

ZigBee wireless technology used in this project has shown reliable real time data transmission. The XBee pro series 2 modules, which operate within the ZigBee protocol, are cheap in comparison to other wireless technologies. The range of communication of the XBee modules is sufficient for this project. The C8051 microcontroller by SiLab, which is a fully integrated mixed-signal system-on-a-chip microcontroller, has proved to be efficient in analog and digital signal processing and suitable for serial communication. The k-means algorithm used in this project for data clustering has shown similar results when compared with the data obtained from individuals in four emotional states. Based on these parameters the developed software has shown a recognition rate of 86.25% across all four emotions.

The four emotions showed variation in data output, a generalized statement of observation for the four emotions, with the 3 different sensors are as follows: For

the neutral state, a normal BPM value, a low rate of change of BPM, a mid-range skin conductance response and a normal to high skin temperature was observed. For the happy state, a high BPM value, a high rate of change of BPM, a high skin conductance response and a normal to low skin temperature was observed. For the angry state a high BPM value, high rate of change of BPM, a high skin conductance response and a high skin temperature was observed. And for the sad state a lower than normal bpm value, low rate of change of bpm, a low skin conductance response and a normal to low skin temperature was observed. Along with emotion recognition and evaluation, the designed system is capable of recognizing physiological changes that arise because of various health conditions. This shows that the system has other advantages along with emotion recognition.

The developed system has therefore achieved its objectives of attaining low cost, non-intrusive and low power physiological sensors capable of detecting four basic emotions in a comfortable manner.

10.0 Future Development

For future improvement and development of the system, the use of additional physiological sensors such as blood pressure sensor, respiration sensor, muscle activity sensor and other sensors, is required. In this project we have only used heart rate, skin temperature and skin conductance sensors, therefore the use of additional sensors will provide more information about the physiological parameters which in turn will improve the recognition rate of the system. Similarly, for data clustering and emotion evaluation we have used k-means algorithm with Euclidean distance measurement in this project. In order to get more information from the data, other clustering methods should be looked into which can help in improving emotion recognition rate.

Addition of more emotional states i.e. fear, stress, panic, will helping in broadening the view of emotions, as currently only four basic emotions are evaluated.

For future improvement, the use of ZigBee modules for data collection along with transmission is put forth. This will eliminate the use of the microcontroller which will help in reducing power consumption, cost and size. However, for signal processing the software would require programming which is currently achieved by programming the microcontroller.

The sensors developed in this project are compact and can be integrated into a computer mouse which will continuously monitor physiological signals of computer users and evaluate their emotions. This approach can benefit computer users in offices, schools, universities, and other institutes where it is used for long hours.

The developed system will become a part of a bigger project known as “Integrated home management system for the elderly”, where it will be used for monitoring physiological parameters as well as the emotions to improve the life of elderly people staying at home.

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12.0 Publications

Proceedings and Conference Papers

1. M. T. Quazi and S. C. Mukhopadhyay, “Continuous Monitoring of Physiological Parameters using Smart Sensors”. International Conference on Sensing Technology (ICST) 2011, Palmerston North New Zealand, pp. 490-495, Nov 28 – Dec 1, 2011.

Seminars

1. M. T. Quazi, “Human Emotion Recognition Using Smart Sensors”, Electronics, Information and Communication System (EICS) Seminar, 21st March 2011. Massey University, Palmerston North, New Zealand.
2. M. T. Quazi, “Human Emotion Recognition Using Smart Sensors”, IEEE Instrumentation and Measurement Society New Zealand Chapter Workshop, 10th March 2011. Auckland University of Technology (AUT), Auckland, New Zealand

13.0 Appendices

Microcontroller Code:

```
// Target:          C8051F02x
// Tool chain:      Keil C51 7.50 / Keil EVAL C51
// Command Line:    None

//-----
// Includes
//-----

#include <c8051f020.h>      // SFR declarations
#include <stdio.h>

//-----
// 16-bit SFR Definitions for 'F02x
//-----

sfr16 ADC0      = 0xbe;    // ADC0 data
sfr16 RCAP2     = 0xca;    // Timer2 capture/reload
sfr16 RCAP3     = 0x92;    // Timer3 capture/reload
sfr16 TMR2      = 0xcc;    // Timer2
sfr16 TMR3      = 0x94;    // Timer3

//-----
// Global Constants
//-----

#define BAUDRATE      9600    // Baud rate of UART in bps
#define SYSCLK        22118400 // External Crystal Osc clock
#define INT_DEC       256     // Integrate and decimate ratio
#define SAR_CLK       2500000 // Desired SAR clock speed
#define SAMPLE_RATE   50000   // Sample frequency in Hz
#define k             6000000 // 3000000
#define SAMPLE_DELAY  1200
#define ANALOG_INPUTS 8       // Number of AIN pins to
                                //measure (min=1, max=8)

//-----
// Function Prototypes
//-----

void OSCILLATOR_Init (void);
void PORT_Init (void);
void UART0_Init (void);
void ADC0_Init (void);
void TIMER3_Init (int counts);
void TIMER0_Init (void);
void ADC0_ISR (void);
void TIMER3_ISR (void);
void INTO_ISR (void);
void UART0_ISR (void);
void TIMER0_ISR (void);

void small_delay (char d); // 8 bit, about 0.34us per count
                             // @22.1MHz
void large_delay (char d); // 16 bit, about 82us per count
                             // @22.1MHz
void huge_delay (char d);  // 24 bit, about 22ms per count
```

```

// @22.1MHz

//-----
// Global Variables
//-----
long Result[ANALOG_INPUTS];           // ADC0 decimated value,
                                       // one for each analog
                                       // input
unsigned char amux_input=0;            // index of analog MUX
                                       // inputs
unsigned char amux_convert=0;
unsigned long BPM_T_count_value = 0;
unsigned long BPM_Tick_Counter = 0;
unsigned int BPM = 0;

//-----
// main() Routine
//-----

void main (void)
{
    unsigned char i;
    EA = 0;
    WDTCN = 0xde;                       // Disable watchdog timer
    WDTCN = 0xad;

    OSCILLATOR_Init ();
    PORT_Init ();
    UART0_Init ();
    ADC0_Init ();
    TIMER3_Init (SYSCLK/SAMPLE_RATE);
    TIMER0_Init ();

    ADOEN = 1;                          // Enable ADC

    EA = 1;                             // Enable global
    interrupts

    while (1)
    {
        if (BPM_T_count_value !=0)
        {
            BPM = k/BPM_T_count_value;
        }
        else
            BPM = 0;

        for(i=0; i<ANALOG_INPUTS; i++)
        {

            printf("%ld#%ld#%ld#%ld#\n", Result[1]*2430/4095, BPM,
                Result[7]*2430/4095, Result[6]*2430/4095);

            huge_delay(12); // Settling time for the sensors
        }
    }
}
//-----

```

```

void OSCILLATOR_Init (void)
{
    int i;                // delay counter

    OSCXCN = 0x67;        // start external oscillator
                          // with 22.1184MHz crystal

    for (i=0; i < 256; i++); // wait for oscillator to start

    while (!(OSCXCN & 0x80)); // Wait for crystal osc. to
                          // settle

    OSCICN = 0x88;        // select external oscillator
                          // as SYSCLK
                          // source and enable missing
                          // clock
                          // detector
}

//-----

void PORT_Init (void)
{
    XBR0      = 0x04;      // Route UART0 to crossbar
    XBR1      = 0x14;      // XBR1: Initial Reset Value
    XBR2      = 0x40;      // Enable crossbar, weak pull-ups
    POMDOUT   |= 0x01;     // enable TX0 as a push-pull
                          // output
    P1MDOUT   |= 0x40;     // enable LED as push-pull output
    ITO       = 1;         // INTO edge triggered
    EX0       = 1;         // enabled external interrupt
                          // INTO
}

//-----

void UART0_Init (void)
{
    SCON0     = 0x50;      // SCON0: mode 1, 8-bit UART,
                          // enable RX
    TMOD      |= 0x20;     // TMOD: timer 1, mode 2, 8-bit
                          // reload
    TH1       = 0x70;      // 9600
    TR1       = 1;         // start Timer1
    CKCON     |= 0x10;     // Timer1 uses SYSCLK as time
                          // base. T1M=1
    PCON      |= 0x80;     // SMOD00 = 1
    T10       = 1;         // Indicate TX0 ready
    RI0       = 0;         // Clear received interrupt flag
}

//-----

void ADC0_Init (void)
{
    ADCOCN = 0x04;        // ADC0 disabled; normal
                          // tracking mode; ADC0

```

```

// conversions are initiated
// on overflow of Timer3; ADC0
// data is right-justified

REFOCN = 0x07; // Enable temp sensor, on-chip
// VREF, and VREF output buffer

AMXOCF = 0x00; // AIN inputs are single-ended
// (default)

AMXOSL = 0x00; // Select AIN0.0 pin as ADC
// mux input ISR will change
// this to step through inputs

ADCOCF = 0x38; // ADC conversion clock =
// 2.5MHz
ADCOCF |= 0x00; // PGA gain = 1 (default)

EIE2 |= 0x02; // enable ADC interrupts
}

//-----

Void TIMER0_Init (void)
{
    CKCON |= 0x08; // Timer 0 uses system clock
// TOM = 1
    TMOD |= 0x02; // Timer 0 in Mode 2 auto
// reload
    TLO = 0xFF;
    TH0 = 0x22; // Timer 0 reload (34)
    TR0 = 1; // Start Timer 0
    ET0 = 1; // Enable interrupt request
// for timer 0
}

//-----

Void TIMER3_Init (int counts)
{
    TMR3CN = 0x02; // Stop Timer3; Clear TF3; set
// SysClk as time base

    RCAP3 = -counts; // Init reload values
    TMR3 = 0xffff; // Set to reload immediately
    EIE2 |= 0x01; // Enable Timer3 interrupts
    TMR3CN |= 0x04; // start Timer3
}

//-----

Void ADC0_ISR (void) interrupt 15
{
    static unsigned int_dec=INT_DEC; // Integrate/decimate
// counter we post a new
// result when int_dec=0

```

```

static long accumulator[ANALOG_INPUTS] = {0L};
// Here's where we
// integrate the ADC
// samples from input
// AI NO.0

unsigned char i;

AD0INT = 0; // clear ADC conversion
// complete overflow

accumulator[amux_convert] += ADC0; // Read ADC value and
// add to running total

if(amux_convert == (ANALOG_INPUTS-1)) // reset input index if
// the last input
// was just read
{
    int_dec--; // Update decimation
// counter when last of
// the analog inputs
// sampled
}

if (int_dec == 0) // If zero, then post
// result
{
    int_dec = INT_DEC; // Reset counter

    for(i=0; i<ANALOG_INPUTS; i++)
    {
        Result[i] = accumulator[i] >> 8; //Copy decimated values
// into Result
        accumulator[i] = 0L; // Reset accumulators
    }
}

amux_convert = amux_input; // now that conversion
// results are stored,
// advance index to the
// analog input
// currently selected on
// the mux
}

//-----

void TIMER3_ISR(void) interrupt 14
{
    TMR3CN &= ~0x80; // acknowledge interrupt

    amux_input++; // step to the next
// analog mux input

    if(amux_input == ANALOG_INPUTS) // reset input index if
// the last input
// was just read
    {
        amux_input=0; // reset input index
// back to AI NO.0
    }

    AMXOSL = amux_input; // select the next input

```

```

// on the analog
// multiplexer
}

//-----

void TIMERO_ISR (void) interrupt 1
{
    TFO = 0; // reset timer overflow flag
    BPM_Tick_Counter++; // tick count for BPM
}

//-----

void INTO_ISR(void) interrupt 0 // for BPM Calculation
{
    if (35000 <= BPM_Tick_Counter && BPM_Tick_Counter <=150000)
        //40-200 BPM range
    {
        BPM_T_count_value = BPM_Tick_Counter;
    }

    BPM_Tick_Counter = 0;
}

//-----

void small_delay(char d)
{
    while (d--);
}

void large_delay(char d)
{
    while (d--)
        small_delay(255);
}

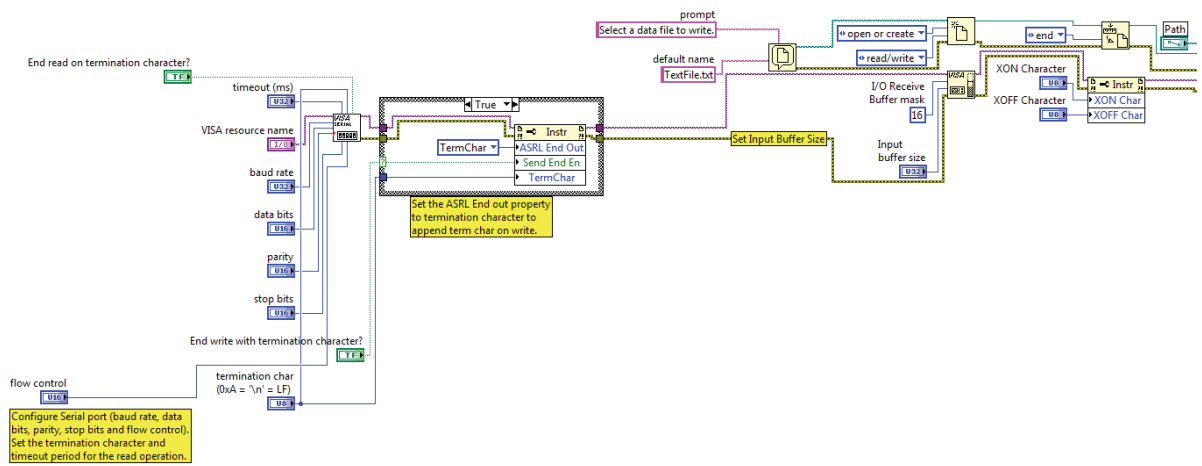
void huge_delay(char d)
{
    while (d--)
        large_delay(255);
}

//-----
// End Of File
//-----

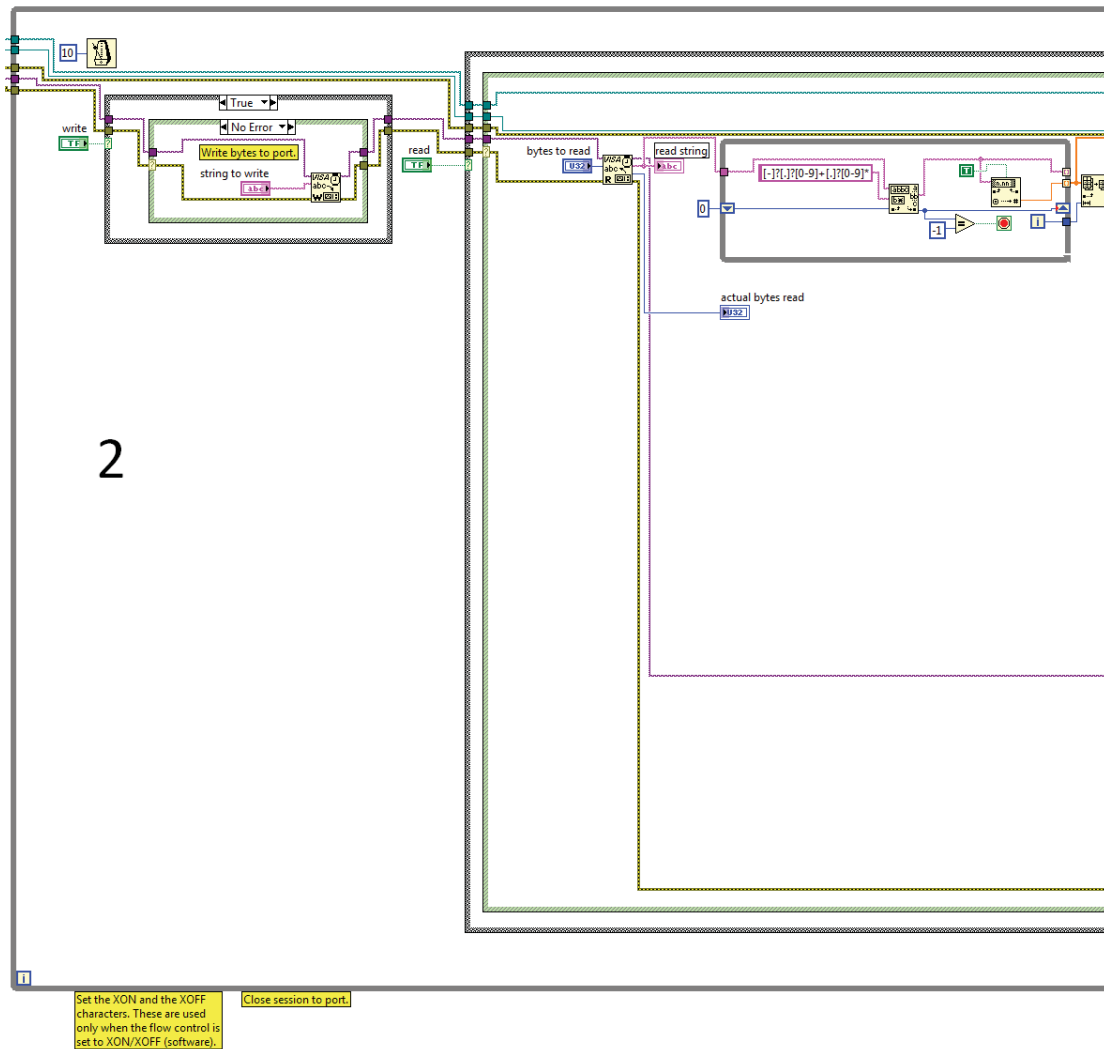
```

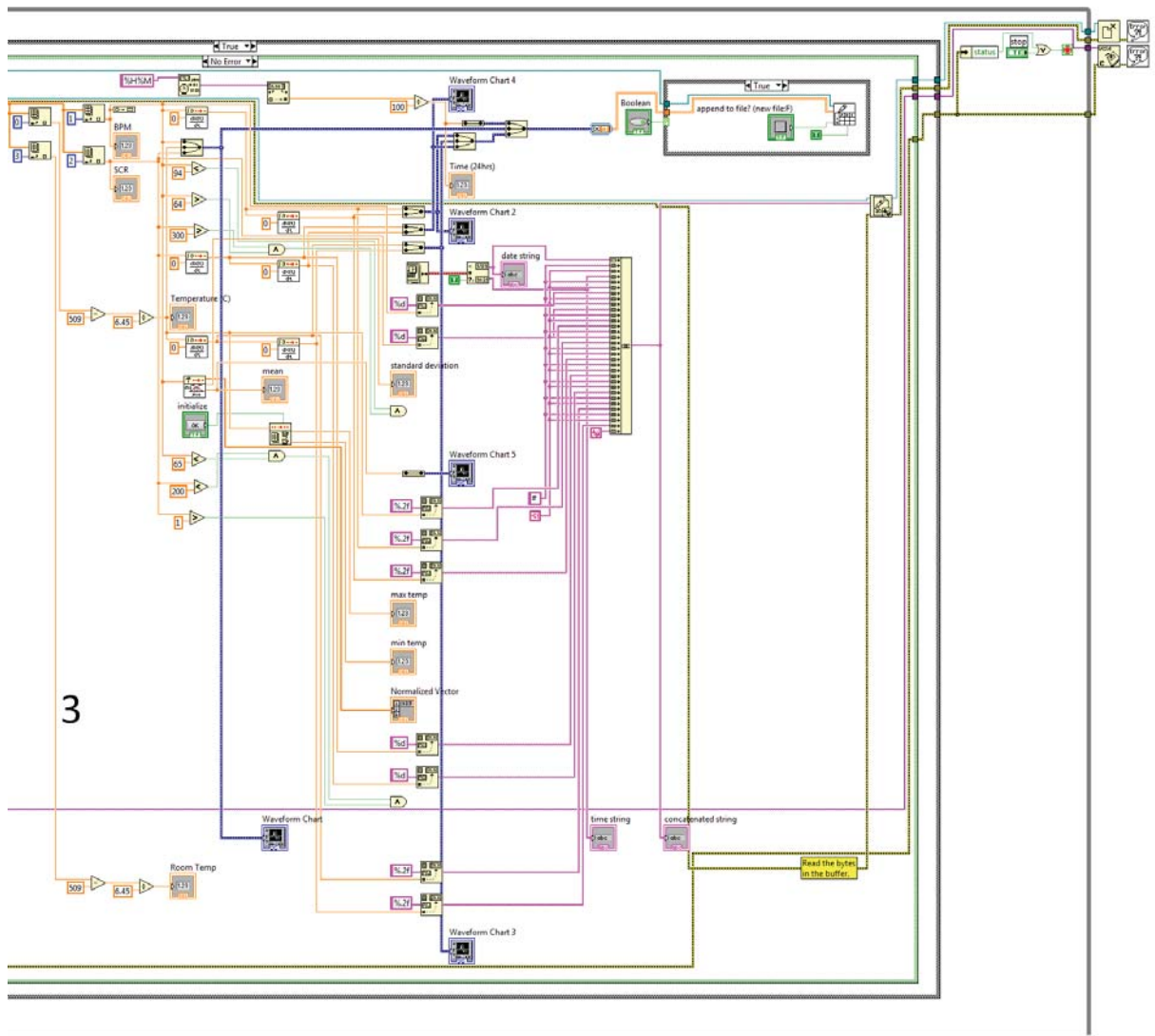
LabView Block diagram:

1



2





C# code:

FORM 1 (Front panel and serial communication)

Public Class Form1

Dim tickStart As Integer = 0

Dim c As Integer = 0

Dim hrc As Integer = 0

Public Shared tempe As Double = 0

'Public Shared temp1 As Double = 0

'Public Shared temp2 As Double = 0

Public Shared tempavg As Double = 0

Public Shared rtemp As Double = 0

Public Shared rtemp1 As Double = 0

Public Shared rtempavg As Double = 0

Public Shared hr As Double = 0

```

Public Shared hr1 As Double = 0
Public Shared hr2 As Double = 0
Dim hrsum As Double = 0
Dim hrsum1 As Double = 0
Dim havg1 As Double = 0
Dim d1hrsum As Double = 0
Dim d1hrsum1 As Double = 0
Public Shared havg As Double = 0
Dim d1havg As Double = 0
Public Shared d1havg1 As Double = 4
Public Shared SCR As Double = 0
Public Shared SCR1 As Double = 0
Public Shared SCR2 As Double = 0
Public Shared SCRavg As Double = 0
Dim temparray(60000) As Double
Dim barray(60000) As Double
Dim SCRarray(60000) As Double
Dim d1temp(60000) As Double
Dim d1hr(60000) As Double
Dim d1SCR(60000) As Double
Dim d2temp(60000) As Double
Dim d2hr(60000) As Double
Dim d2SCR(60000) As Double
Public Shared f As Double
Public Inco, infile As String
Public panicflag As String
Public Temp1 = "0"
Public Temp2 = "0"
Public Temp3 = "0"
Public Temp4 = "0"
Public Bval17, Bval18, Bval19, Bval10
Dim file_content As String = ""
    Public wmsg = 0
Public patternstring As String
Public pstr As String
Private Sub Form1_Load(ByVal sender As System.Object, ByVal e As
System.EventArgs) Handles MyBase.Load
    For i As Integer = 0 To _
        My.Computer.Ports.SerialPortNames.Count - 1
        ComboBox1.Items.Add( _
            My.Computer.Ports.SerialPortNames(i))
    Next
    CheckBox1.Visible = True
    cgraph1()
    TextBox1.Text = Now
End Sub

```

```

Private Sub cgraph1()
    Dim myPane As GraphPane = ZedGraphControl6.GraphPane
    myPane.Title.Text = "Emotion Features"
    myPane.XAxis.Title.Text = "Time, Seconds"
    myPane.YAxis.Title.Text = "Emotion"
    myPane.YAxis.IsVisible = True
    ' Save 1200 points. At 50 ms sample rate, this is one minute
    ' The RollingPointPairList is an efficient storage class that always
    ' keeps a rolling set of point data without needing to shift any data values
    Dim list As New RollingPointPairList(1200)
    Dim list1 As New RollingPointPairList(1200)
    Dim list2 As New RollingPointPairList(1200)
    Dim list3 As New RollingPointPairList(1200)
    Dim list4 As New RollingPointPairList(1200)
    ' Initially, a curve is added with no data points (list is empty)
    ' Color is blue, and there will be no symbols
    'Dim curve As Lineltem = myPane.AddCurve("Emotion Features", list, Color.Blue,
SymbolType.None)
    Dim curve As Lineltem = myPane.AddCurve("Sad", list, Color.Gray)
    Dim curve1 As Lineltem = myPane.AddCurve("Angry", list1, Color.Red)
    Dim curve2 As Lineltem = myPane.AddCurve("Neutral", list2, Color.SpringGreen)
    Dim curve3 As Lineltem = myPane.AddCurve("Happy", list3, Color.RoyalBlue)
    Dim curve4 As Lineltem = myPane.AddCurve("Place Hand on Device", list4,
Color.SandyBrown)
    ' Sample at 50ms intervals
    Timer6.Interval = 10
    Timer6.Enabled = True
    Timer6.Start()
    myPane.XAxis.Scale.Min = 0
    myPane.XAxis.Scale.Max = 30
    myPane.XAxis.Scale.MinorStep = 1
    myPane.XAxis.Scale.MajorStep = 5
    ZedGraphControl6.AxisChange()
    tickStart = Environment.TickCount
End Sub
Private Sub cgraph3()
    Timer6.Interval = 1000
    Timer6.Enabled = True
    Timer6.Start()
End Sub
Private Sub Button1_Click(ByVal sender As Object, ByVal e As System.EventArgs)
Handles Button1.Click
    If Button1.Text Is "Open Port" Then
        SerialPort1.PortName = ComboBox1.Text
        SerialPort1.Open()
        Button1.Text = "Close Port"
    End If
End Sub

```

```

Elseif Button1.Text Is "Close Port" Then
    SerialPort1.Close()
    Button1.Text = "Open Port"
End If
End Sub
Private Sub SerialPort1_DataReceived(ByVal sender As Object, ByVal e As
System.IO.Ports.SerialDataReceivedEventArgs) Handles SerialPort1.DataReceived
    Dim Inco As String
    Dim i As Integer
    f = 0.0
    Dim val1, val2, val3, val4 As String
    'Dim aval1, aval2, aval3, aval4, aval5, aval6 As String
    'Dim val86, val87 As String
    'Dim val76, val77 As String
    'Dim val96, val97 As String
    'Dim val16, val17 As String
    'Dim tempval, humval As String
    Inco = SerialPort1.ReadLine
    c = c + 1
    i = Inco.Length
    If i = 16 Or i = 17 Or i = 18 Then
        Dim eparts As String() = Inco.Split(New Char() {"#"c})
        val1 = eparts(0)
        val2 = eparts(1)
        val3 = eparts(2)
        val4 = eparts(3)
        tempe = (Double.Parse(val1) - 509) / 6.45
        tempe = tempe.ToString("f2")
        hr = val2
        SCR = val3
        rtemp = (Double.Parse(val4) - 509) / 6.45
        rtemp = rtemp.ToString("f2")
        temparray(c) = tempe
        bpararray(c) = hr
        SCRarray(c) = SCR
        'd1SCR(c - 1) = (SCR - (SCRarray(c - 2)))
        'd2temp(c - 1) = (d1temp(c) - d1temp(c - 2))
        'd2hr(c - 1) = (d1hr(c) - d1hr(c - 2))
        'd2SCR(c - 1) = (d1SCR(c) - d1SCR(c - 2))
        'Console.Write("RT:" & rtemp)
        'Console.Write(",")
        'Console.Write("| ")
        Console.Write("T:" & tempe)
        Console.Write(",")
        Console.Write("| ")
        Console.Write("HR" & hr)
    End If
End Sub

```

```

Console.Write(",")
If c = 1 Then
    hrsum = barray(c)
End If
hrsum = barray(c - 1) + barray(c)
'Console.Write(hrsum)
'Console.Write(",")
hravg = hrsum / 2
hravg = hravg.ToString("f2")
'Console.Write(hravg)
'Console.Write(",")
'Console.Write("| ")
Console.Write("Havg:" & hravg)
Console.Write(",")
'Console.Write(c)
'Console.Write(",")
If c = 1 Then
    'Console.Write("inside")
    d1hr(c) = 0
    d1hrsum = 0
    d1hravg = 0
Else
    d1hr(c) = Math.Abs((barray(c) - barray(c - 1)))
    If d1hr(c) > 15 Then
        d1hr(c) = 0
    End If
    'Console.Write(barray(c))
    'Console.Write(barray(c - 1))
    'Console.Write(",")
    d1hrsum = d1hrsum + d1hr(c)
    d1hravg = d1hrsum / c
    d1hravg = d1hravg.ToString("f2")
    Console.Write("d1hr(c):" & d1hr(c))
    Console.Write(",")
    Console.Write("d1hravg:" & d1hravg)
    Console.Write(",")
    'Console.Write(c)
    Console.Write("| ")
    Console.Write("SCR:" & SCR)
    Console.Write(",")
End If

If SCR <= 1 Then
    f = 1
    Console.Write("Waiting!!")
    Console.WriteLine(",")

```

```

End If

If (hravg <= 85 And SCR > 1) Then

    If SCR > 1 And SCR < 130 Then
        f = 10.0
        Console.Write("Cluster 3-Sad")
        Console.WriteLine(",")
    End If
    If (SCR >= 130) Then
        f = 30.0
        Console.Write("Cluster 0-Neutral")
        Console.WriteLine(",")
    End If
    'If (SCR >= 600) Then
    'f = 20.0
    'Console.Write("Cluster 2-Angry")
    'Console.WriteLine(",")
    'End If
End If
If hravg > 85 And SCR > 1 Then
    ' If ((SCR > 1 And SCR < 450) Or (d1hravg < 4)) Then
    'f = 20.0
    'Console.Write("Cluster 2-Angry")
    'Console.WriteLine(",")
    'End If
    If (SCR >= 450 And SCR < 600) Then
        f = 40.0
        Console.Write("Cluster 1-Happy")
        Console.WriteLine(",")
    End If

    If (SCR >= 600) Then
        f = 20.0
        Console.Write("Cluster 2-Angry")
        Console.WriteLine(",")
    End If
End If

    Dim ch As String
ch = checkproc()
Dim MyTextFile As New System.IO.StreamWriter("c:\tauseef.txt", True)
If ch = "check" Then
    MyTextFile.Write(Now)
    MyTextFile.Write(",")
    MyTextFile.Write(rtemp)

```

```

        MyTextFile.Write(",")
        MyTextFile.Write(tempe)
        MyTextFile.Write(",")
        MyTextFile.Write(d1temp(c))
        MyTextFile.Write(",")
        MyTextFile.Write(d2temp(c))
        MyTextFile.Write(",")
        MyTextFile.Write(hr)
        MyTextFile.Write(",")
        MyTextFile.Write(d1hr(c))
        MyTextFile.Write(",")
        MyTextFile.Write(d2hr(c))
        MyTextFile.Write(",")
        MyTextFile.Write(hravg)
        MyTextFile.Write(",")
        MyTextFile.Write(d1hravg)
        MyTextFile.Write(",")
        MyTextFile.Write(SCR)
        MyTextFile.Write(",")
        MyTextFile.Write(d1SCR(c))
        MyTextFile.Write(",")
        MyTextFile.Write(d2SCR(c))
        MyTextFile.WriteLine(",")
        MyTextFile.Close()
    End If
    MyTextFile.Close()
End If
End Sub

Public Function checkproc() As String
    Dim Rec As String = ""
    If CheckBox1.Checked = True Then
        Rec = "check"
    End If
    If CheckBox1.Checked = False Then
        Rec = "Uncheck"
    End If
    Return Rec
End Function

Private Sub cal_avg(ByVal t As Double, ByVal h As Double, ByVal g As Double)
End Sub

Private Sub Button2_Click(ByVal sender As System.Object, ByVal e As
System.EventArgs) Handles Button2.Click
    Dim form2 As New Form2
    form2.Show()
End Sub

```

```

Private Sub Button3_Click(ByVal sender As System.Object, ByVal e As
System.EventArgs) Handles Button3.Click
    Dim form3 As New Form3
    form3.Show()
End Sub
Private Sub Button4_Click(ByVal sender As System.Object, ByVal e As
System.EventArgs) Handles Button4.Click
    Dim form4 As New Form4
    form4.Show()
End Sub
Private Sub Button5_Click(ByVal sender As System.Object, ByVal e As
System.EventArgs)
    OpenFileDialog1.Title = "Please Select a File"
    OpenFileDialog1.InitialDirectory = "C:temp"
    OpenFileDialog1.ShowDialog()
End Sub
Private Sub Button6_Click(ByVal sender As System.Object, ByVal e As
System.EventArgs)
End Sub
Private Sub OpenFileDialog1_FileOk(ByVal sender As Object, ByVal e As
System.ComponentModel.CancelEventArgs) Handles OpenFileDialog1.FileOk
    Dim strm As System.IO.Stream
    strm = OpenFileDialog1.OpenFile()
End Sub
Private Sub Button6_Click_1(ByVal sender As System.Object, ByVal e As
System.EventArgs) Handles Button6.Click
    Me.Close()
End Sub
Private Sub Timer1_Tick(ByVal sender As Object, ByVal e As System.EventArgs)
Handles Timer6.Tick
End Sub
Private Sub Button5_Click1(ByVal sender As Object, ByVal e As System.EventArgs)
Handles Button5.Click
    Dim form6 As New Form6
    form6.Show()
End Sub
Private Sub Timer6_Tick(ByVal sender As System.Object, ByVal e As
System.EventArgs) Handles Timer6.Tick
    'Dim curve As Lineltem = myPane.AddCurve("Emotion Features", list, Color.Blue,
SymbolType.None)
    If ZedGraphControl6.GraphPane.CurveList.Count <= 0 Then Return
    'Dim curve As Lineltem = ZedGraphControl6.GraphPane.CurveList(0)
    Dim curve As Lineltem = ZedGraphControl6.GraphPane.CurveList(0)
    Dim curve1 As Lineltem = ZedGraphControl6.GraphPane.CurveList(1)
    Dim curve2 As Lineltem = ZedGraphControl6.GraphPane.CurveList(2)
    Dim curve3 As Lineltem = ZedGraphControl6.GraphPane.CurveList(3)

```



```

Dim curve4 As LineItem = ZedGraphControl6.GraphPane.CurveList(4)
If curve Is Nothing Then Return
Dim list As IPointListEdit = curve.Points
Dim list1 As IPointListEdit = curve1.Points
Dim list2 As IPointListEdit = curve2.Points
Dim list3 As IPointListEdit = curve3.Points
Dim list4 As IPointListEdit = curve4.Points
If list Is Nothing Then Return
Dim time As Double = (Environment.TickCount - tickStart) / 1000.0
If Form1.f = 1 Then
    list4.Add(time, Form1.f)
End If
If Form1.f = 10 Then
    list.Add(time, Form1.f)
End If
If Form1.f = 20 Then
    list1.Add(time, Form1.f)
End If
If Form1.f = 30 Then
    list2.Add(time, Form1.f)
End If
If Form1.f = 40 Then
    list3.Add(time, Form1.f)
End If
Dim xScale As Scale = ZedGraphControl6.GraphPane.XAxis.Scale
If time > xScale.Max - xScale.MajorStep Then
    xScale.Max = time + xScale.MajorStep
    xScale.Min = xScale.Max - 30.0
End If
ZedGraphControl6.AxisChange()
ZedGraphControl6.Invalidate()
Me.Refresh()
End Sub

```

End Class

Form 2 (Skin Temperature Graph)

```

Imports ZedGraph
Imports Zedgraph_sample.Form1
Public Class Form2
    Dim tickStart As Integer = 0
    Private Sub Form2_Load(ByVal sender As Object, ByVal e As System.EventArgs)
Handles Me.Load
        cgraph1()
        TextBox1.Text = Now
    End Sub

```

```

End Sub
Private Sub cgraph1()
    Dim myPane As GraphPane = ZedGraphControl1.GraphPane
    myPane.Title.Text = "Temperature Monitoring"
    myPane.XAxis.Title.Text = "Time, Seconds"
    myPane.YAxis.Title.Text = "Avg Temperature Deg(C)"
    ' Save 1200 points. At 50 ms sample rate, this is one minute
    ' The RollingPointPairList is an efficient storage class that always
    ' keeps a rolling set of point data without needing to shift any data values
    Dim list As New RollingPointPairList(1200)
    ' Initially, a curve is added with no data points (list is empty)
    ' Color is blue, and there will be no symbols
    Dim curve As LineItem = myPane.AddCurve("Temperature", list, Color.Blue,
SymbolType.None)
    ' Sample at 50ms intervals
    Timer1.Interval = 50
    Timer1.Enabled = True
    Timer1.Start()
    ' Just manually control the X axis range so it scrolls continuously
    ' instead of discrete step-sized jumps
    myPane.XAxis.Scale.Min = 0
    myPane.XAxis.Scale.Max = 30
    myPane.XAxis.Scale.MinorStep = 1
    myPane.XAxis.Scale.MajorStep = 5
    ' Scale the axes
    ZedGraphControl1.AxisChange()
    ' Save the beginning time for reference
    tickStart = Environment.TickCount
End Sub

Private Sub Timer1_Tick(ByVal sender As System.Object, ByVal e As
System.EventArgs) Handles Timer1.Tick
    ' Make sure that the curvelist has at least one curve
    If ZedGraphControl1.GraphPane.CurveList.Count <= 0 Then Return
    ' Get the first CurveItem in the graph
    Dim curve As LineItem = ZedGraphControl1.GraphPane.CurveList(0)
    If curve Is Nothing Then Return
    ' Get the PointPairList
    Dim list As IPointListEdit = curve.Points
    ' If this is null, it means the reference at curve.Points does not
    ' support IPointListEdit, so we won't be able to modify it
    If list Is Nothing Then Return
    ' Time is measured in seconds
    Dim time As Double = (Environment.TickCount - tickStart) / 1000.0
    'Math.Sin(2.0 * Math.PI * time / 3.0)
    ' 3 seconds per cycle
    list.Add(time, Form1.tempe)

```

```

' Keep the X scale at a rolling 30 second interval, with one
' major step between the max X value and the end of the axis
Dim xScale As Scale = ZedGraphControl1.GraphPane.XAxis.Scale
If time > xScale.Max - xScale.MajorStep Then
    xScale.Max = time + xScale.MajorStep
    xScale.Min = xScale.Max - 30.0
End If
' Make sure the Y axis is rescaled to accommodate actual data
ZedGraphControl1.AxisChange()
' Force a redraw
ZedGraphControl1.Invalidate()
Me.Refresh()
End Sub

Private Sub Form1_Resize(ByVal sender As System.Object, ByVal e As
System.EventArgs) Handles MyBase.Resize
    'SetSize()
End Sub

' Set the size and location of the ZedGraphControl
Private Sub SetSize()
    ' Control is always 10 pixels inset from the client rectangle of the form
    Dim formRect As Rectangle = Me.ClientRectangle
    formRect.Inflate(-10, -10)
    If ZedGraphControl1.Size <> formRect.Size Then
        ZedGraphControl1.Location = formRect.Location
        ZedGraphControl1.Size = formRect.Size
    End If
End Sub

Private Sub Button1_Click(ByVal sender As Object, ByVal e As System.EventArgs)
Handles Button1.Click
    Me.Close()
End Sub
End Class

```

Form 3 (Heart Rate graph)

```

Imports ZedGraph
Imports Zedgraph_sample.Form1

Public Class Form3
    Dim tickStart2 As Integer = 0

    Private Sub cgraph2()
        Dim myPane2 As GraphPane = ZedGraphControl2.GraphPane

```

```

myPane2.Title.Text = "Heart Rate"
myPane2.XAxis.Title.Text = "Time, Seconds"
myPane2.YAxis.Title.Text = "Heart Rate"

' Save 1200 points. At 50 ms sample rate, this is one minute
' The RollingPointPairList is an efficient storage class that always
' keeps a rolling set of point data without needing to shift any data values
Dim list2 As New RollingPointPairList(1200)

' Initially, a curve is added with no data points (list is empty)
' Color is blue, and there will be no symbols
Dim curve2 As LineItem = myPane2.AddCurve("Heart Rate", list2,
Color.GreenYellow, SymbolType.Diamond)

' Sample at 50ms intervals
Timer2.Interval = 50
Timer2.Enabled = True
Timer2.Start()

' Just manually control the X axis range so it scrolls continuously
' instead of discrete step-sized jumps
myPane2.XAxis.Scale.Min = 0
myPane2.XAxis.Scale.Max = 30
myPane2.XAxis.Scale.MinorStep = 1
myPane2.XAxis.Scale.MajorStep = 5
' Scale the axes
ZedGraphControl2.AxisChange()
' Save the beginning time for reference
tickStart2 = Environment.TickCount
End Sub

Private Sub Timer2_Tick(ByVal sender As System.Object, ByVal e As
System.EventArgs) Handles Timer2.Tick
' Make sure that the curvelist has at least one curve
If ZedGraphControl2.GraphPane.CurveList.Count <= 0 Then Return
' Get the first CurveItem in the graph
Dim curve2 As LineItem = ZedGraphControl2.GraphPane.CurveList(0)
If curve2 Is Nothing Then Return
' Get the PointPairList
Dim list2 As IPointListEdit = curve2.Points
' If this is null, it means the reference at curve.Points does not
' support IPointListEdit, so we won't be able to modify it
If list2 Is Nothing Then Return
' Time is measured in seconds
Dim time2 As Double = (Environment.TickCount - tickStart2) / 1000.0
'Math.Sin(2.0 * Math.PI * time / 3.0)
' 3 seconds per cycle

```

```

list2.Add(time2, Form1.hr)
' Keep the X scale at a rolling 30 second interval, with one
' major step between the max X value and the end of the axis
Dim xScale2 As Scale = ZedGraphControl2.GraphPane.XAxis.Scale
If time2 > xScale2.Max - xScale2.MajorStep Then
    xScale2.Max = time2 + xScale2.MajorStep
    xScale2.Min = xScale2.Max - 30.0
End If
' Make sure the Y axis is rescaled to accommodate actual data
ZedGraphControl2.AxisChange()
' Force a redraw
ZedGraphControl2.Invalidate()
End Sub

Private Sub Form3_Load(ByVal sender As Object, ByVal e As System.EventArgs)
Handles Me.Load
    cgraph2()
    TextBox1.Text = Now
End Sub

Private Sub Form2_Resize(ByVal sender As System.Object, ByVal e As
System.EventArgs) Handles MyBase.Resize
    'SetSize()
End Sub

' Set the size and location of the ZedGraphControl
Private Sub SetSize2()
    ' Control is always 10 pixels inset from the client rectangle of the form
    Dim formRect As Rectangle = Me.ClientRectangle
    formRect.Inflate(-10, -10)
    If ZedGraphControl2.Size <> formRect.Size Then
        ZedGraphControl2.Location = formRect.Location
        ZedGraphControl2.Size = formRect.Size
    End If
End Sub

Private Sub Button1_Click(ByVal sender As System.Object, ByVal e As
System.EventArgs) Handles Button1.Click
    Me.Close()

End Sub
End Class

```

Form 4 (Skin Conductance Response graph)

Imports ZedGraph

```

Imports Zedgraph_sample.Form1
Public Class Form4
    Dim tickStart4 As Integer = 0
    Private Sub cgraph4()
        Dim myPane4 As GraphPane = ZedGraphControl4.GraphPane
        myPane4.Title.Text = "SCR"
        myPane4.XAxis.Title.Text = "Time, Seconds"
        myPane4.YAxis.Title.Text = "SCR"
        ' Save 1200 points. At 50 ms sample rate, this is one minute
        ' The RollingPointPairList is an efficient storage class that always
        ' keeps a rolling set of point data without needing to shift any data values
        Dim list4 As New RollingPointPairList(1200)
        ' Initially, a curve is added with no data points (list is empty)
        ' Color is blue, and there will be no symbols
        Dim curve4 As LineItem = myPane4.AddCurve("SCR", list4, Color.RosyBrown,
SymbolType.Circle)
        ' Sample at 50ms intervals
        Timer4.Interval = 50
        Timer4.Enabled = True
        Timer4.Start()
        ' Just manually control the X axis range so it scrolls continuously
        ' instead of discrete step-sized jumps
        myPane4.XAxis.Scale.Min = 0
        myPane4.XAxis.Scale.Max = 30
        myPane4.XAxis.Scale.MinorStep = 1
        myPane4.XAxis.Scale.MajorStep = 5
        ' Scale the axes
        ZedGraphControl4.AxisChange()
        ' Save the beginning time for reference
        tickStart4 = Environment.TickCount
    End Sub
    Private Sub Timer2_Tick(ByVal sender As System.Object, ByVal e As
System.EventArgs) Handles Timer4.Tick
        ' Make sure that the curvelist has at least one curve
        If ZedGraphControl4.GraphPane.CurveList.Count <= 0 Then Return
        ' Get the first CurveItem in the graph
        Dim curve4 As LineItem = ZedGraphControl4.GraphPane.CurveList(0)
        If curve4 Is Nothing Then Return
        ' Get the PointPairList
        Dim list4 As IPointListEdit = curve4.Points
        ' If this is null, it means the reference at curve.Points does not
        ' support IPointListEdit, so we won't be able to modify it
        If list4 Is Nothing Then Return
        ' Time is measured in seconds
        Dim time4 As Double = (Environment.TickCount - tickStart4) / 1000.0
        'Math.Sin(2.0 * Math.PI * time / 3.0)
    End Sub
End Class

```

```

' 3 seconds per cycle
list4.Add(time4, Form1.SCR)
' Keep the X scale at a rolling 30 second interval, with one
' major step between the max X value and the end of the axis
Dim xScale4 As Scale = ZedGraphControl4.GraphPane.XAxis.Scale
If time4 > xScale4.Max - xScale4.MajorStep Then
    xScale4.Max = time4 + xScale4.MajorStep
    xScale4.Min = xScale4.Max - 30.0
End If
' Make sure the Y axis is rescaled to accommodate actual data
ZedGraphControl4.AxisChange()
' Force a redraw
ZedGraphControl4.Invalidate()
End Sub
Private Sub Form3_Load(ByVal sender As Object, ByVal e As System.EventArgs)
Handles Me.Load
    cgraph4()
    TextBox1.Text = Now
End Sub
Private Sub Form2_Resize(ByVal sender As System.Object, ByVal e As
System.EventArgs) Handles MyBase.Resize
    'SetSize()
End Sub
' Set the size and location of the ZedGraphControl
Private Sub SetSize2()
    ' Control is always 10 pixels inset from the client rectangle of the form
    Dim formRect As Rectangle = Me.ClientRectangle
    formRect.Inflate(-10, -10)
    If ZedGraphControl4.Size <> formRect.Size Then
        ZedGraphControl4.Location = formRect.Location
        ZedGraphControl4.Size = formRect.Size
    End If
End Sub
Private Sub Button1_Click(ByVal sender As System.Object, ByVal e As
System.EventArgs) Handles Button1.Click
    Me.Close()
End Sub
End Class

```

Form 5 (Four emotion graphs)

```

Imports ZedGraph
Imports Zedgraph_sample.Form1
Public Class Form6
    Dim tickStart As Integer = 0

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Private Sub Form6_Load(ByVal sender As Object, ByVal e As System.EventArgs)
Handles Me.Load
    cgraph1()
    TextBox1.Text = Now
End Sub
Private Sub cgraph1()
    Dim myPane As GraphPane = ZedGraphControl6.GraphPane
    myPane.Title.Text = "Emotion Features"
    myPane.XAxis.Title.Text = "Time, Seconds"
    myPane.YAxis.Title.Text = "Emotion parameters"
    ' Save 1200 points. At 50 ms sample rate, this is one minute
    ' The RollingPointPairList is an efficient storage class that always
    ' keeps a rolling set of point data without needing to shift any data values
    Dim list As New RollingPointPairList(1200)
    Dim list1 As New RollingPointPairList(1200)
    Dim list2 As New RollingPointPairList(1200)
    Dim list3 As New RollingPointPairList(1200)
    Dim list4 As New RollingPointPairList(1200)
    ' Initially, a curve is added with no data points (list is empty)
    ' Color is blue, and there will be no symbols
    'Dim curve As LineItem = myPane.AddCurve("Emotion Features", list, Color.Blue,
SymbolType.None)
    Dim curve As LineItem = myPane.AddCurve("Sad", list, Color.Gray)
    Dim curve1 As LineItem = myPane.AddCurve("Angry", list1, Color.Red)
    Dim curve2 As LineItem = myPane.AddCurve("Neutral", list2, Color.SpringGreen)
    Dim curve3 As LineItem = myPane.AddCurve("Happy", list3, Color.RoyalBlue)
    Dim curve4 As LineItem = myPane.AddCurve("Place Hand on Device", list4,
Color.SandyBrown)
    ' Sample at 50ms intervals
    Timer6.Interval = 10
    Timer6.Enabled = True
    Timer6.Start()
    myPane.XAxis.Scale.Min = 0
    myPane.XAxis.Scale.Max = 30
    myPane.XAxis.Scale.MinorStep = 1
    myPane.XAxis.Scale.MajorStep = 5
    ZedGraphControl6.AxisChange()
    tickStart = Environment.TickCount
End Sub
Private Sub Timer6_Tick(ByVal sender As System.Object, ByVal e As
System.EventArgs) Handles Timer6.Tick
    'Dim curve As LineItem = myPane.AddCurve("Emotion Features", list, Color.Blue,
SymbolType.None)
    If ZedGraphControl6.GraphPane.CurveList.Count <= 0 Then Return
    'Dim curve As LineItem = ZedGraphControl6.GraphPane.CurveList(0)
    Dim curve As LineItem = ZedGraphControl6.GraphPane.CurveList(0)

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Dim curve1 As LineItem = ZedGraphControl6.GraphPane.CurveList(1)
Dim curve2 As LineItem = ZedGraphControl6.GraphPane.CurveList(2)
Dim curve3 As LineItem = ZedGraphControl6.GraphPane.CurveList(3)
Dim curve4 As LineItem = ZedGraphControl6.GraphPane.CurveList(4)

If curve Is Nothing Then Return
Dim list As IPointListEdit = curve.Points
Dim list1 As IPointListEdit = curve1.Points
Dim list2 As IPointListEdit = curve2.Points
Dim list3 As IPointListEdit = curve3.Points
Dim list4 As IPointListEdit = curve4.Points

If list Is Nothing Then Return
Dim time As Double = (Environment.TickCount - tickStart) / 1000.0
If Form1.f = 1 Then
    list4.Add(time, Form1.f)
End If
If Form1.f = 10 Then
    list.Add(time, Form1.f)
End If
If Form1.f = 20 Then
    list1.Add(time, Form1.f)
End If
If Form1.f = 30 Then
    list2.Add(time, Form1.f)
End If
If Form1.f = 40 Then
    list3.Add(time, Form1.f)
End If

Dim xScale As Scale = ZedGraphControl6.GraphPane.XAxis.Scale
If time > xScale.Max - xScale.MajorStep Then
    xScale.Max = time + xScale.MajorStep
    xScale.Min = xScale.Max - 30.0
End If
ZedGraphControl6.AxisChange()
ZedGraphControl6.Invalidate()
Me.Refresh()
End Sub

Private Sub Form1_Resize(ByVal sender As System.Object, ByVal e As
System.EventArgs) Handles MyBase.Resize
    'SetSize()
End Sub

' Set the size and location of the ZedGraphControl
Private Sub SetSize()
    ' Control is always 10 pixels inset from the client rectangle of the form

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    Dim formRect As Rectangle = Me.ClientRectangle
    formRect.Inflate(-10, -10)
    If ZedGraphControl6.Size <> formRect.Size Then
        ZedGraphControl6.Location = formRect.Location
        ZedGraphControl6.Size = formRect.Size
    End If
End Sub

Private Sub Button1_Click(ByVal sender As Object, ByVal e As System.EventArgs)
Handles Button1.Click
    Me.Close()
End Sub
End Class
```