Activity-aware Stress Sensory System

by

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14958

Dissertation submitted in partial fulfillment of

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CERTIFICATION OF APPROVAL

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Approved by,

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(A.P. Dr. Tang Tong Boon)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

January 2015

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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MATTHEW TIE TUNG YU

ABSTRACT

Continuous stress monitoring may able to help analyzing and enhance the awareness of an individual on their stress patterns and provide more reliable data information for physicians in interventions. In the past years research, studies on mental stress sensory system were limited inside laboratory environment. However, excluding the effects of physical activity can be impractical while developing a wearable stress sensory system for daily use. In this project, effects of external factors from environment on Galvanic Skin Response (GSR) measurements and integration of several stress sensory system were studied. Electrocardiogram (ECG), GSR, and Activity Recognition System (ARS) were studied under different physical activities: sitting, standing, lying and walking. It is showed from the studies that an overall accuracy of 94.7% in ARS is achieved by using two sensor node system (at thigh and ankle each) which an improvement of 27.3% from using single sensor node system. It is further demonstrated that ARS could help improve in accuracy of wearable stress sensory system.

ACKNOWLEDGMENT

I would like to express my heartfelt gratitude to my supervisor, Assoc. Professor Dr. Tang Tong Boon for giving me the opportunity to do this project on the topic of Development of an Activity Recognition System Using Accelerometers, which also led me to do lot researches and came to know about many new things and the capacity of Electrical and Electronic Engineering. Through his guidance and encouragement, the project has been successfully accomplished.

Furthermore, I am sincerely grateful to those who have helped me in giving constructive criticism and friendly advice during the project work, especially my course mates. I would also like to thank my peers especially those who had been my subjects for experiment to gather data for analysis. Nevertheless, I express my warm thanks to all the examiners and judges of Poster Presentation and ELECTREX for sharing their illuminating views on a number of issues related to the project.

Lastly, I would also like to thank my parents and friends who have encouraged and supported me throughout the process.

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CHAPTER 1: INTRODUCTION

1.1 Background

In this decade, stress had become a common and major problem to the modern society. In most of the time, people are unaware of being under stress for example when they occupied with deadlines in certain projects or works. This deleterious effect of stress is usually defined as the short-term sympathetic nervous system activation which is caused by cognitive stressors [1, 2]. However, long-term exposure to stress can be chronic and people may not be aware on the existence of it. Chronic stress can result in serious problem including increases in blood pressure, weakening body immune system, muscle pain, increases in risk of heart attack and stroke, depression[3, 4] and so on.

Stress can be literally defined as the physiological response on the mental and physical challenges encountered by human being. In another word, it is better to be explained as a way for human body to prepare itself from facing challenging and difficult situation with heightened alertness. Besides, stress can also be a physiological response that serves as linking mechanism from stressor to its target organ.[5] The sudden threats from stress can provoke the “fight or flight” response (acute stress response) and cause human nervous system to secrete a flood of stress hormones, such as adrenaline and cortisol to intensify the concentration of the bloodstream. Chronic stress is difficult to be managed since it cannot be measured in a timely way.[6] A continuous monitoring on individual’s stress levels is essential to perform individual stress management and control. There are numbers of physiological parameters are used for stress monitoring such as heart rate, skin conductance level, respiration activity and blood pressure. These parameters are widely used in recent technology in monitoring individual stress levels and track closely on the changes [7]. With the advancement of today technology, stress monitoring devices have been developed to measure and monitor the stress level of an individual from time to time.[8] Furthermore, the increasing of wearable stress monitoring devices had improved in measuring daily stress levels of an individual and monitoring the healthy stress condition. This paper aims to improve the continuous stress monitoring in Galvanic Skin Response (GSR) system by integrating with Activity Recognition System (ARS).

1.2 Problem Statement

There are a lot of evidence shows that stress can be one of the most common factors which contribute in work related ill health, sickness absence and lower down the work performance of employees.[9] Based on the Japan government's Comprehensive Survey of Living Conditions (2005), the percentage of participants involved who suffered in daily life or work stress is up to 48.2%. While in the 2000 European Working Conditions Survey (EWCS), it is found that the second most common work-related health problem is work related stress across the EU.[10, 11] Studies showed that chronic stress can lead to not only increases the risk of depression and neurological disorders such as stroke, but also significant rewiring of brain circuitries, alteration in neuronal morphology and changes in neurogenesis [12]. Long-term exposure under this chronic stress can cause serious health problems and unwanted status. Based on The World Health Organization (WHO), it is estimated that health problem caused by chronic stress cost American businesses approximately $300 billion dollars annually [13].

Previous studies on mental stress are mostly limited to indoor laboratory environment which exclude the parameter of human daily activities [8]. Hence continuous stress monitoring are being developed in nowadays technology to enhance the reliability and accuracy of mental stress levels and to track the flow of an individual stress symptoms based on daily activities. In order for an individual to monitor on personal stress levels, wearable stress monitoring devices are developed to monitor mental stress of an individual continuously.

Throughout the research studies and prototype construction, the selection of stress recognition system and activity recognition system are very important in monitoring an individual's stress level and the integrated system must not interfering individual's daily activities [14]. The sensors selected must be carefully filtered based on the criteria above in order to provide the most reliable data information. Thus in order to achieve high accuracy wearable stress monitoring system, GSR system and ARS will be integrated.

1.3 Objectives

- To integrate GSR and ARS system to measure mental stress under various daily activities (walking, sitting, standing & laying).
- To refine the accuracy of wearable mental stress sensory system in monitoring human stress level daily.

1.4 Scope of Study

The focus on the project will be on developing a multi-parametric wearable mental stress monitoring system with the ability of monitoring mental stress level under human daily movement activities. It is important to understand the consequences and impacts chronic stress can lead to. People who are unaware on the stress symptoms may bring themselves unnecessary troubles and health problems.

The preliminary symptoms of stress would be studied to understand and investigate on the secretion of hormones such as adrenaline and cortisol during stress threat. Besides that, physiological signals such as heart rate (HR), skin conductance level (SCL), heart rate variability (HRV), Electrocardiography (ECG), Electroencephalogram (EEG) and activity of sympathetic and para-sympathetic nervous system.

In order to develop an activity-aware stress sensory system, the theory and operation of stress sensory system and activity recognition system are studied. The integration of these systems is crucial to determine and verify the status of user movement activities using activity recognition system and measure the stress level based on the data gathered from the activity recognition system. Throughout this paper, the impact and consequences of stress, symptoms of mental stress and integration of stress detection system with activity recognition system will be discussed.

CHAPTER 2: LITERAUTRE REVIEW

In order to succeed in developing an activity-aware stress sensory system for long-term monitoring, the system must achieve a balance in both data information content and comfort. Thus it is essential to study and find out the most suitable stress monitoring sensor which can measure the physiological parameters that are relevant, yet without interfering individual's daily activities. Since the mental stress will trigger human body to induced intense physiological response, the physiological signals making themselves the best path into stress monitoring [14]. Based on previous studies, a lot of physiological signals have shown to correlate with mental stress levels, including blood pressure, skin conductance [15], electrodermal activity (EDA), heart rate, heart rate variability (HRV) and skin temperature. In this paper, one of the physiological parameters will be discussed and investigated on the suitability of developing multi-parametric wearable stress monitoring system.

2.1 Galvanic Skin Response (GSR)

The galvanic skin response (GSR) is known to be a simple and useful electrophysiological technique to monitor the sweat gland nerve response by measuring the changes in the electrical conductance of the skin in response to various kind of incoming stress [16-18]. Based on the history, GSR can also be known as the sympathetic skin response (SSR) or skin conductance response (SCR). The concept mechanism of GSR is basically response to the changes in electrical resistance across two skin region by applying small value voltage to monitor on the rapid change of current.

However, GSR do have some limitations which not allow it to be stand alone in mental stress monitoring functionality. There is a well-known phenomenon that amplitude of GSR tends to decrease during repeated stimulations.[17] Besides, the signal response quality of the GSR signal is very dependent on the continuity of the physical contact between GSR electrodes and the individual's skin. This issue is mainly caused by either the individual is having a dry skin or he/she not willing to wearing the device tight enough to ensure on the good contact. Besides, individual whom overwhelmed by motion can critically influence the sensitivity and accuracy of the measurement of skin resistance.

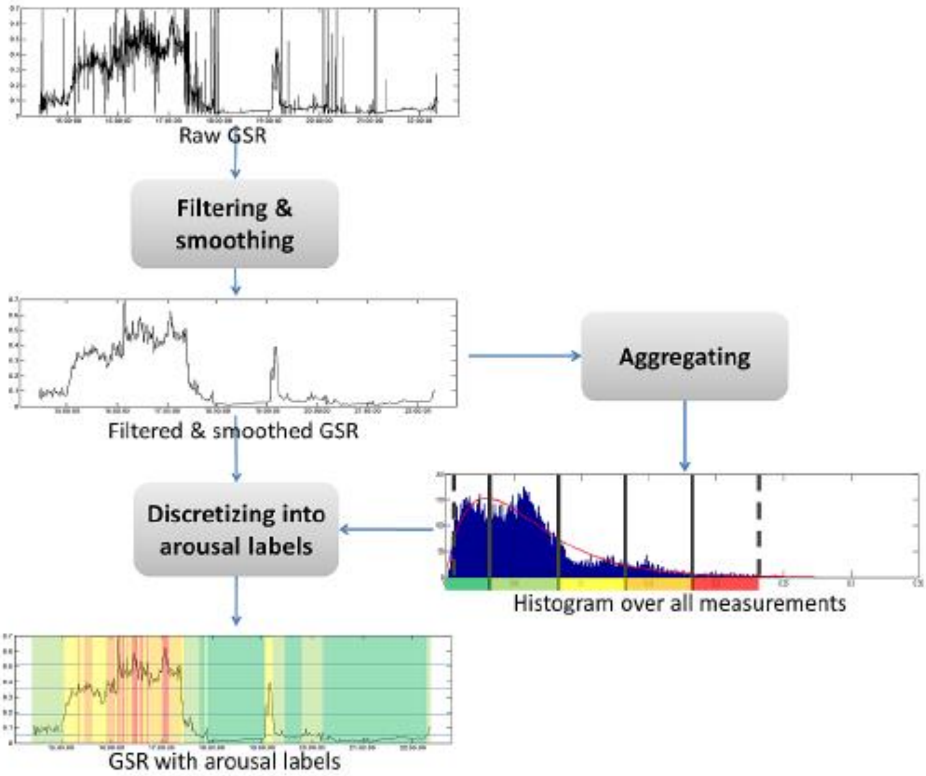

Figure 1: GSR Signal Filtering and Smoothing Flowchart

Due to the external factors such as skin temperature, ambient illumination, and humidity, noises present in the raw GSR signal collected from the sensors. Thus, filtering and smoothing technique is required to filter out signal which is out of the range of 0.48Hz and 4.8Hz.

2.2 Activity Recognition System (ARS)

Activity recognition system can basically categorized into two which are external sensing system and wearable sensing system. Recently, the activity recognition of human daily lifestyle has become a popular topic within the field of biomedical applications [19, 20]. In the recent field of mental stress monitoring, activity recognition system become crucial to identify the activity status of an individual during continuous wearable stress monitoring technology and assist in increasing the accuracy of response feedback.

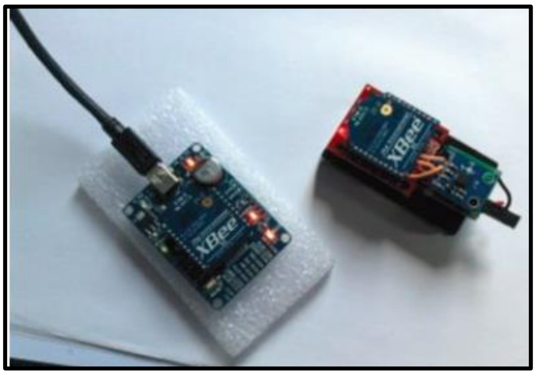

Figure 2: SKXbee Receiver Module (left) and Sensor Node in Operation (right)

The activity recognition sensor node functions to record extensive data information from human body activity in order to analyze and predict the approximate activity performed by the individual. By considering in developing wearable activity recognition system, severe factors such as type of sensors, number of sensors, sensor location and algorithm in classification of activity pattern recognition can be important. Based on previous studies from Dandy[21], triple-axis accelerometer (ADXL335) and microcontroller (Xbee Explorer Regulated) is used to perform activity recognition system with an accuracy achievement of 67.42% with one sensor node system and 94.7% with two sensor node system.

2.4 Summary of Literature Review

Galvanic Skin Response (GSR) is an affordable and cheap solution in monitoring human stress level. Besides, they work quite efficiently without complex programming code and hardware design. However, GSR can be greatly affected by human activities and giving variation of output result which cause it difficult to measure human stress level accurately unless the individual is in steady and relax mode.

In order to overcome in this problem, GSR system with ARS will provide both stress level output and activity identification output to the system to determine the stress level of an individual during carry out of different activities (eg walking, standing, sitting & lying).

CHAPTER 3: METHODOLOGY

3.1 Research Methodology

Several methods have been used in conducting a research on the project topic:

- Literature review on mental stress response relevant journals and its measuring tools.
- Literature review on hardware implementation of Galvanic Skin Response (GSR) and Activity Recognition System (ARS).
- Literature review on GSR raw signal filtering and smoothing from external noises.

3.1.1 Literature review on mental stress response relevant journals and its measuring tools

At the beginning of the project, a better understanding and information on mental stress is required to fully understand the problem statement and objectives of the project. Fundamental knowledge on the causes of stress and stress detecting technique is much crucial in the project.

3.1.2 Literature review on hardware implementation of GSR and ARS

Sensor positioning is important throughout the project since not every part of human skin is sensitive to stress response. Besides, the circuit design of components is studied to prevent waste of components used and ensure the measuring tools construct without any incompatible issues. Therefore, component datasheets and fabrication manual have been utilized fully throughout the project.

3.1.3 Literature review on raw signal filtering and smoothing from noises

Since the objective of the project is to develop a wearable stress sensory system which users are able to use it in their daily activities, consideration of external factors from environment will be crucial to the stress sensory system. It is known that skin temperature, humidity, ambient illumination and variation of human skin conductance can affect much on the sensors output and cause inaccurate result. Thus, literature review and studies on signal filtering and smoothing are required in processing the data information and decision making.

3.2 Project Activities

Throughout this project, two systems were developed to test on the stress level of an individual in different environment and physical activities position.

3.2.1 Block Diagram

Based on the literature review done previously, GSR is known to be a sensitive physiological response detector based on human tense and stress. The activity-aware stress sensory system utilizes the sensitivity of GSR and combines with the data output from ARS. The system functioned to collect both X, Y, Z axis data from accelerometer of two node systems and comparator voltage output from GSR circuit. The output voltage from GSR circuit is filtered by a bandpass filter ranging from 0.48Hz and 4.8Hz and the threshold of stress level is vary depends on physical activity position.

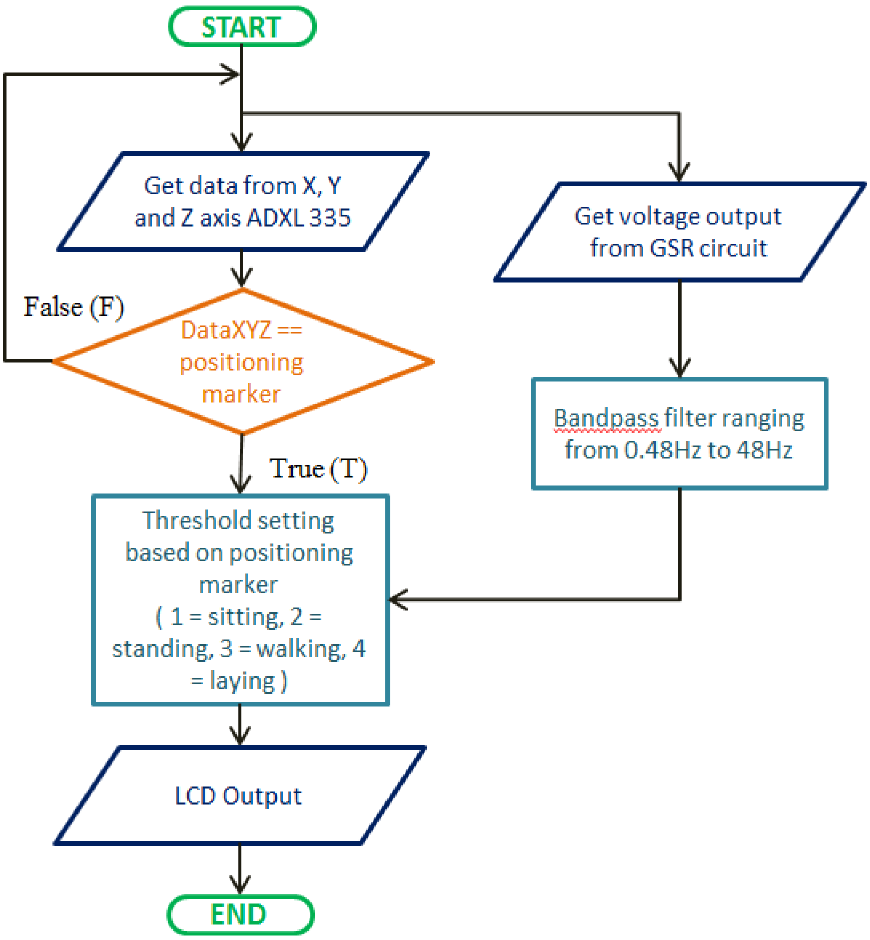

Figure 3: Activity-aware Stress Sensory System Flowchart Diagram

3.3 Hardware Prototype Design

3.3.1 Activity Recognition System (ARS)

Figure below showed the progress of Activity Recognition System (ARS).

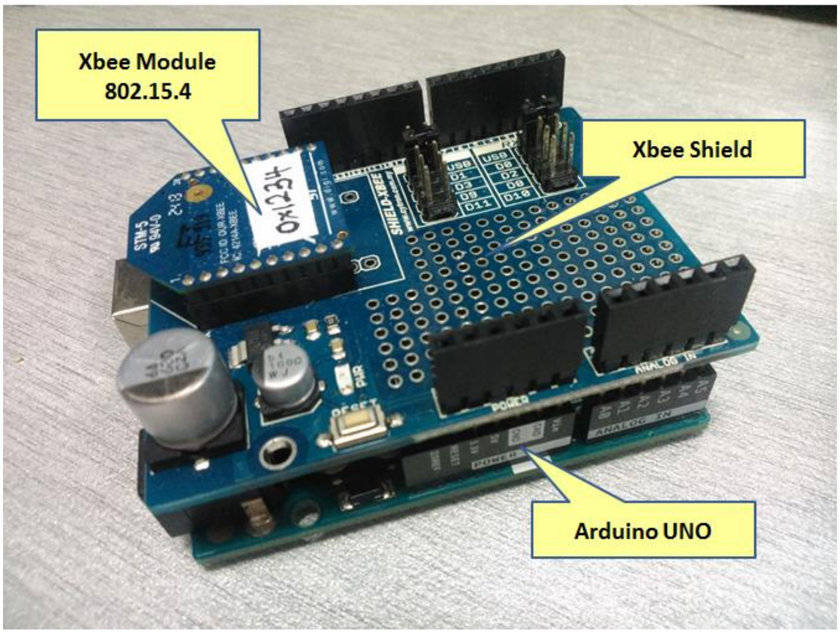

Figure 4: Activity Aware Sensory System Receiver

Xbee Module 802.15.4

- Used to communicate with the accelerometer (ADXL335) sensor nodes.

Xbee Shield

- Act as the communication bridge between Xbee Module and Arduino UNO.

Arduino UNO

- Act as microcontroller to collect information from GSR and ARS, and then process the data into readable stress level threshold.

3.3.2 Galvanic Skin Response (GSR)

Figure below showed the progress of Galvanic Skin Response (GSR) sensor.

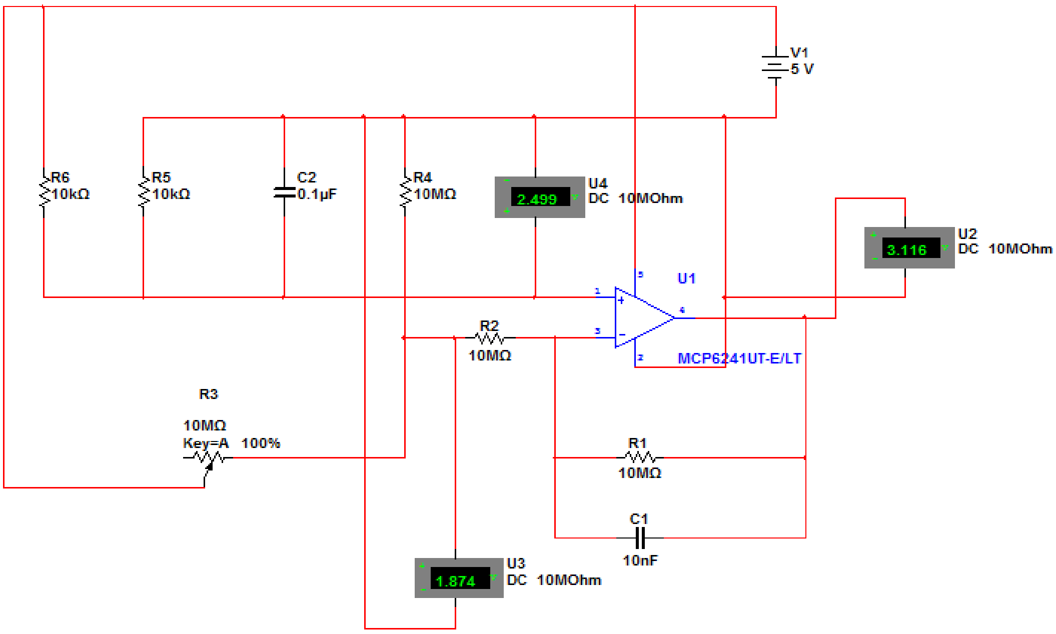

Figure 5: Galvanic Skin Response Sensor Schematic

Based on the figure above, R3 represents the resistance across human body which used for skin conductance measurement. Every individual have a different range in skin resistance of human body, the average resistance of human body is usually ranging from 50kΩ to 100MΩ.

The circuit is connect with a low pass filter (R1 and C1) to remove high frequency noise (60Hz) since GSR is usually a slow signal of 1~2Hz.

The voltage across the body resistance can be calculated as below

$$V_{resisance} = \frac{10M\Omega}{10M\Omega + R3} V_1$$

The output voltage can be calculated as below:

$$V_o \cong \frac{R_1}{R_2}\left(V_{reference} - V_{resistance}\right) + V_{reference}$$

3.3.3 Accelerometer Sensor Nodes

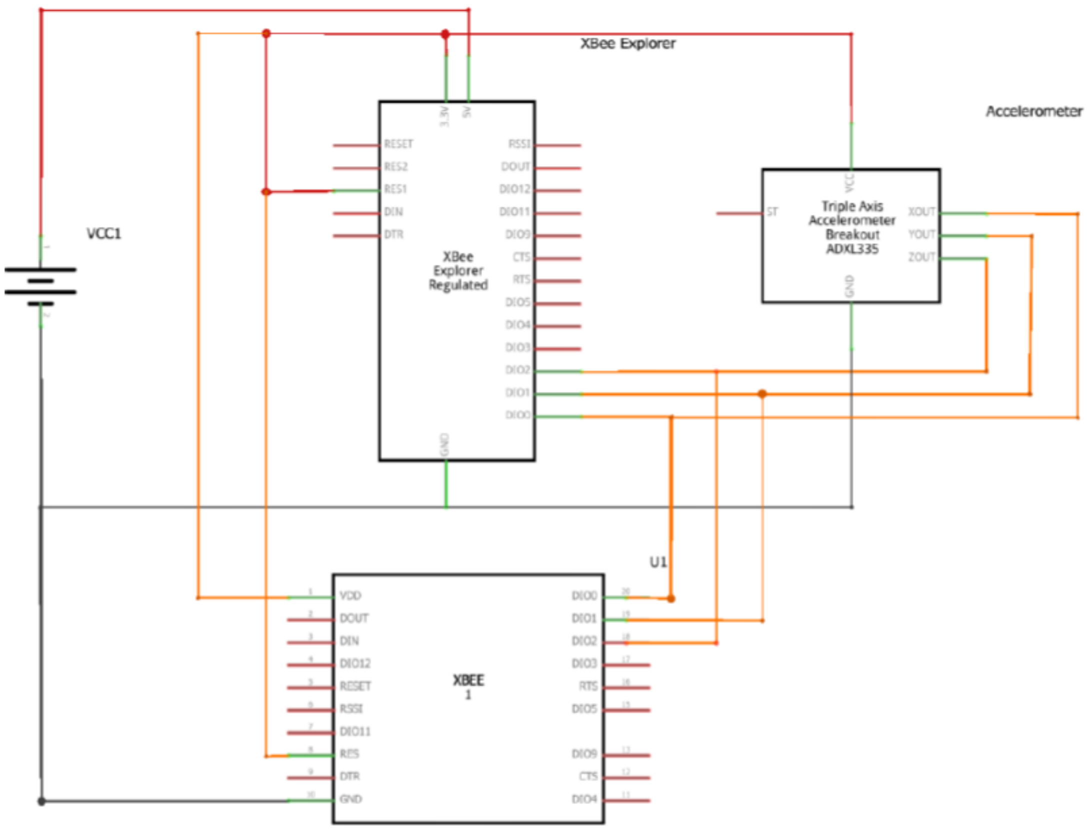

Figure 6: Schematic of Accelerometer Sensor Node Transmitter

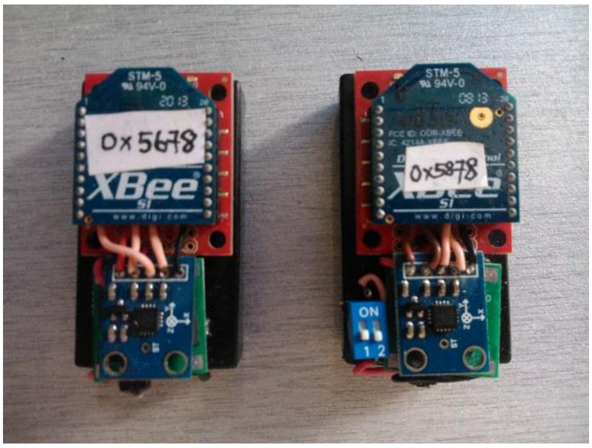

Figure 7: Accelerometer Sensor Node

The schematic diagram for the transmitter was showed in the figure above. For each of the accelerometer sensor node, it weighed approximately 55 grams with a dimension of $7cm \times 3cm \times 1.3cm$.

3.3.3.1 Configuration of XBee Wireless Module

All the XBee wireless modules were programmed as either receiver or transmitter using the software which was provided by the manufacturer (Digi International), named X-CTU. The syntax of the programming is referred from the manual provided by the manufacturer. Baud rate was set to be 115200, 8 data bits, no parity bit and 1 stop bit. Configuration of XBee is configured into AT mode where any data sent to the XBee module is immediately sent to the remote module identified by the Destination Address in memory. When the module is in AT mode, it can be configured by the user or a host microcontroller by first placing the module in Command mode and then sending predefined AT commands through the UART port.

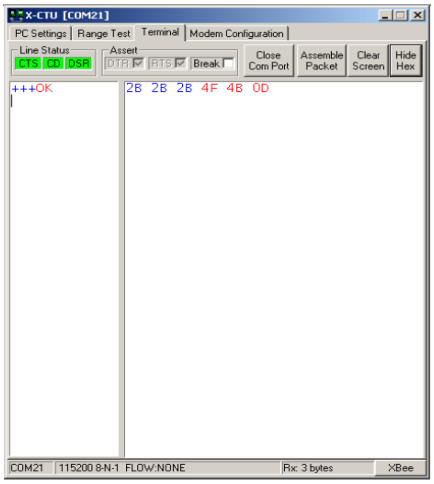

Figure 8: XBee Terminal Tab

The Terminal tab act as a terminal emulator which have the ability to send and receive assemble packet in Hex and ASCII formats. All the configurations related to communication of the wireless modules are done here. The network topology and the address of each node have to be defined and correctly programmed. The instructions to program can be referred from the manual provided online by the manufacturer.

Configuration	Properties
Serial Communication	Baud rate = 115200, 8 data bits, no parity bit, 1 stop bit
Sampling rate / frequency	10ms / 100Hz
Max ADC level	512
Number of receiver	1
Number of sensor node	2
Network topology	Star, many-to-one, unidirectional, IEEE 802.15.0.4
Addressing	Receiver – 0x1234, Transmitter 1 – 0x5678, Transmitter 2 – 0x5778

Table 1: Xbee Configuration Specification

3.4 Prototype Simulation

The results for Multisim simulation on the GSR circuit is shown below:

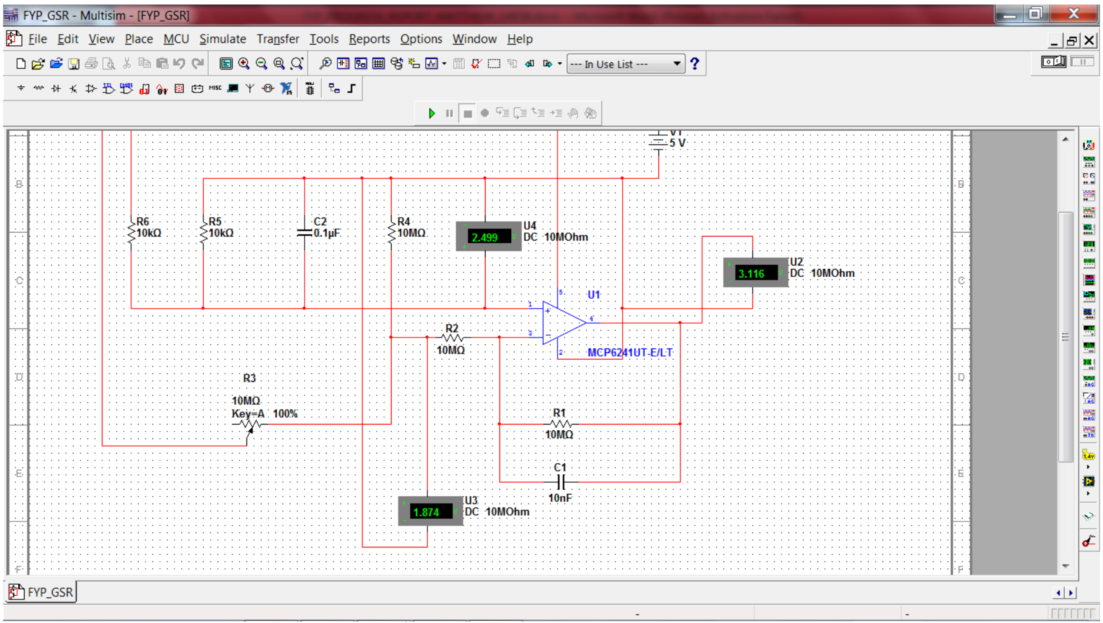

Figure 9: Galvanic Skin Response Schematic Simulation

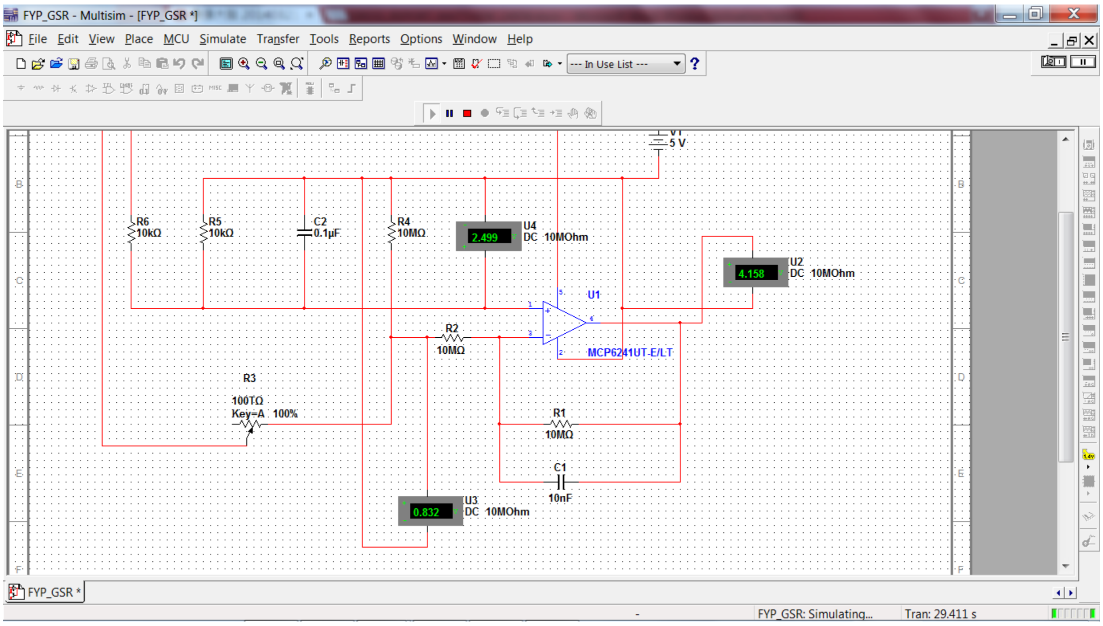

Figure 10: Simulation with R3 Equal to Infinite Value

Based on the stimulation below, the maximum output voltage showed 4.158V when R3 is an infinite value; while the minimum output voltage showed 0.051V when R3 is at a minimum value of 50kΩ.

From the table below, it showed the theoretical value and experimental value of the GSR circuit from MULTISIM simulation and Voltmeter measurement respectively. The percentage error of the circuit is very low.

Besides, it can be shown that whenever the resistance of human skin increase (more relax), the output voltage of the GSR circuit will be decrease.

Resistance	Va (V)	Vo (V)
0	5.00	0.000313
500k	4.456	0.518
1M	4.038	0.952
1.5M	3.706	1.283
2M	3.437	1.553
2.5M	3.214	1.776
3M	3.026	1.964
3.5M	2.865	2.125
4M	2.726	2.262
4.5M	2.605	2.384
5M	2.499	2.491
5.5M	2.405	2.585
6M	2.32	2.669
6.5M	2.245	2.745
7M	2.176	2.813
7.5M	2.114	2.876
8M	2.058	2.932
8.5M	2.006	2.984
9M	1.958	3.031
9.5M	1.914	3.075
10M	1.874	3.114

Table 2: GSR Interface Circuit Voltage Measurement

3.5 Software Development & Simulation

3.5.1 Arduino UNO Galvanic Skin Response

In this project, Arduino UNO is used as microcontroller to collect and analyze GSR and accelerometer data information in order to monitor human stress level in daily life. Thus, simulation on Arduino UNO was performed to observe on human stress.

Figure below showed the program code used for GSR simulation using Arduino UNO.

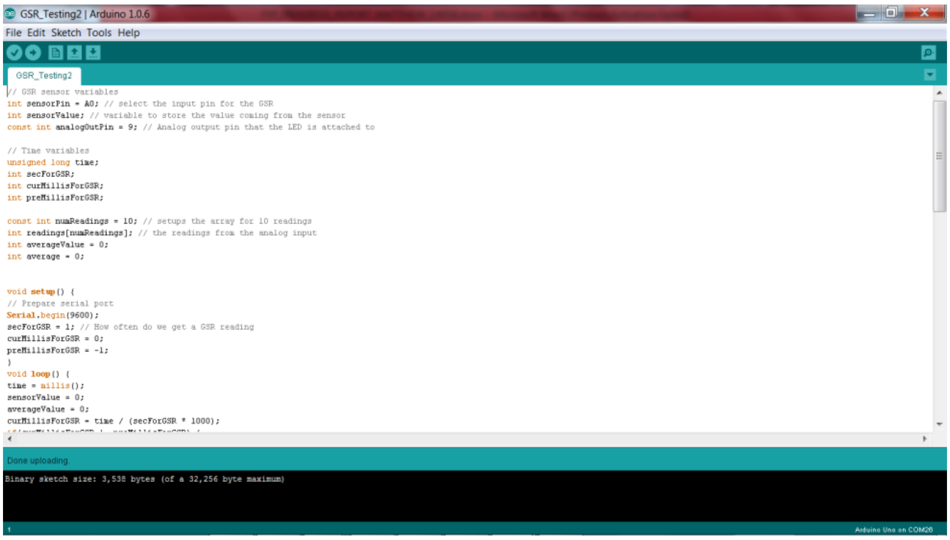

Figure 11: Arduino UNO Program Code for GSR Simulation

Figure below showed the output value from Arduino UNO when GSR system is an open circuit.

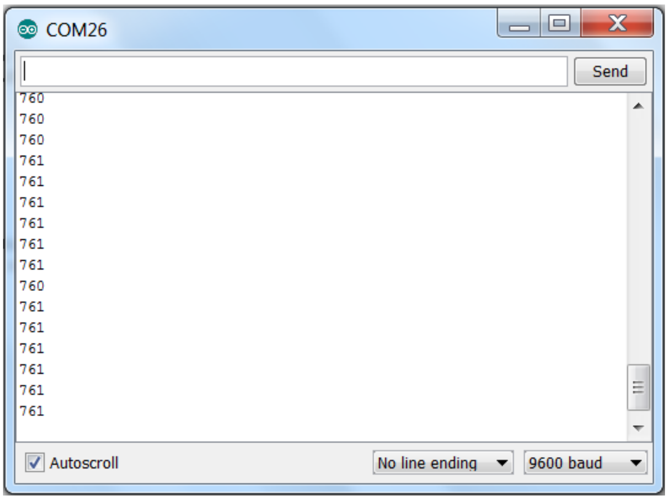

Figure 12: Output Value from Arduino during Open Circuit (no load)

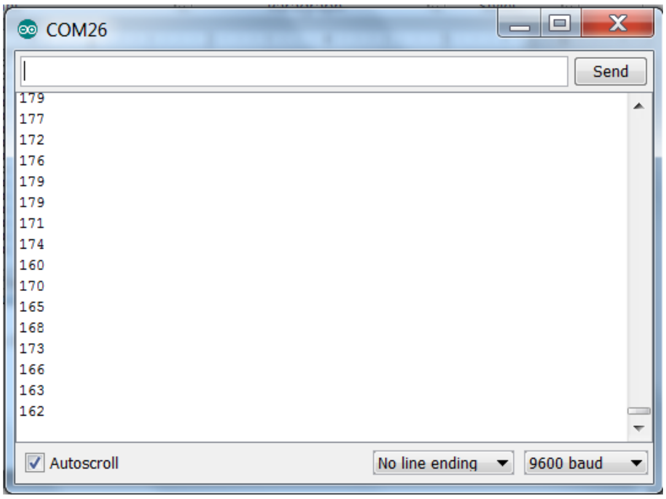

Figure 13: Output Value from Arduino when Individual is sitting

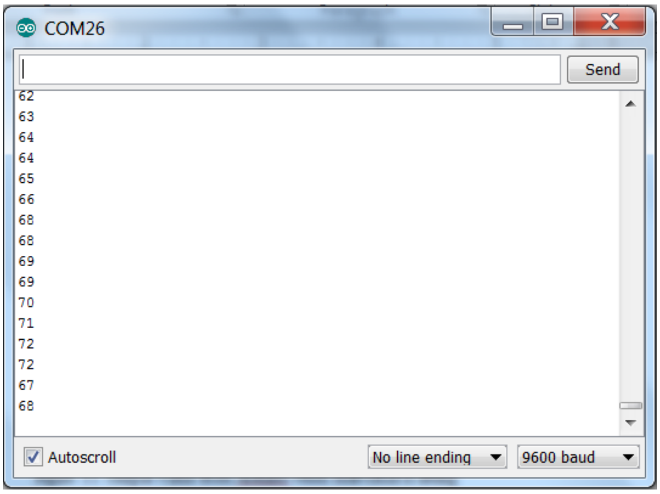

Figure 14: Output Value from Arduino when Individual is walking

Based on the figure above, it can be shown that when the individual is walking, sitting or not contact with the GSR device, the output voltage level obtained from Arduino UNO is varied too. From the output voltage value obtained, it is shown that the average level when individual is not attach to the device is 760.5; while when the individual is sitting and walking with the device attached, the average level are 170.88 and 67.38.

Skin Resistance	Voltage Value	Arduino Value
0	0.000313	0
1M	0.952	60
2M	1.553	125.5
3M	1.964	225.7
4M	2.262	298.3
5M	2.491	354.1
6M	2.669	397.5
7M	2.813	432.6
8M	2.932	461.6
9M	3.031	485.8
10M	3.114	506
∞	4.158	760.5

Table 3: Galvanic Skin Response Arduino Output Level

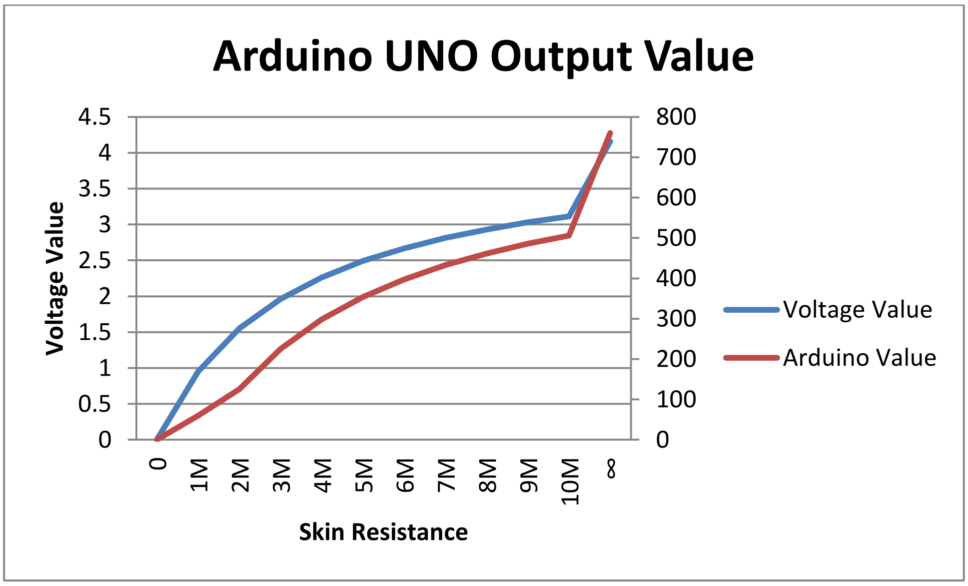

Figure 15: Graph of Arduino UNO Output Value

Based on the figure and table showed above, the output value when an individual is sitting and walking are 170.88 and 67.38, the skin resistance values are around 2.5MΩ and 1MΩ respectively. It is clearly shown that an individual can suffer more stress when walking compare to sitting down calmly.

In the graph below, it is shown the pattern of the GSR response before and after bandpass filter.

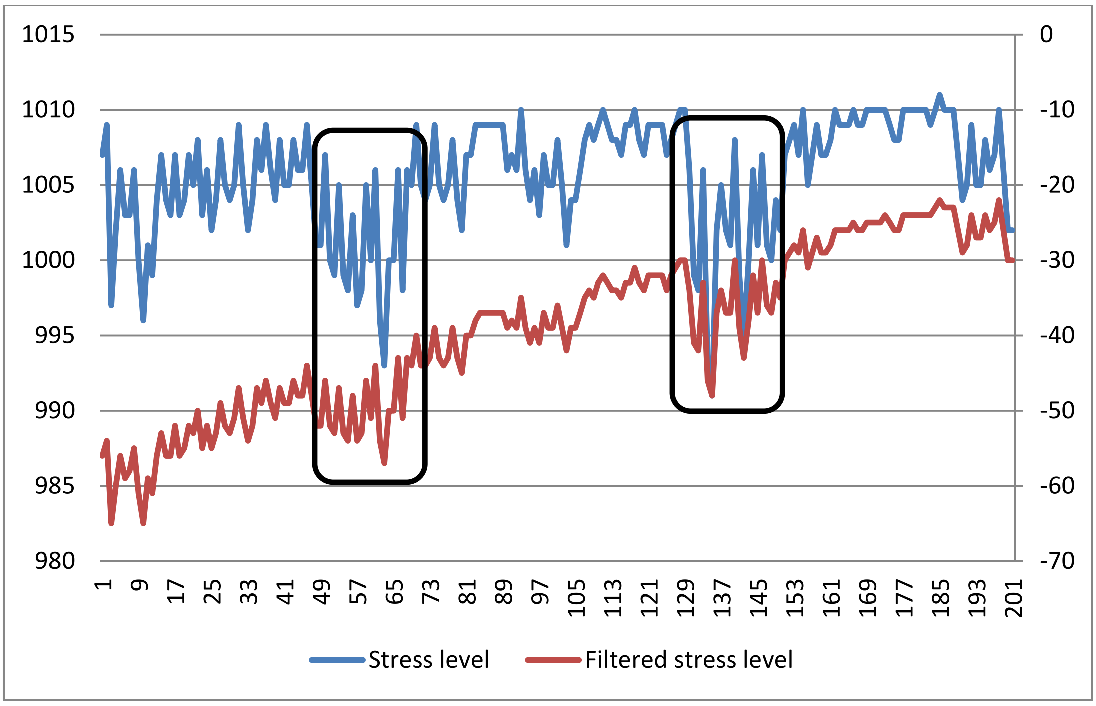

Figure 16: Filtered GSR signal ranging from 0.48Hz to 4.8Hz

The raw GSR signal was first filtered by a low pass filter which filtered out signal frequency higher than 4.8Hz; the signal is then filtered by a high pass filter in the software which filtered out signal frequency lower than 0.48Hz. The bandpass filter captured the arousal response from human skin resistivity and convert it into digital stress level signals.

Fig. 16 showed two high arousal pulses where the subject was asked to repeat sitting and standing position. This is shown that while human subject is in different activity phases, they tense to have different threshold of voltage stress level. Thus, activity recognition system acts as important parameters in determining the threshold changing of stress arousal voltage level.

3.5.2 Arduino UNO Activity Aware Sensory System

Besides the Galvanic Skin Response skin resistance voltage data collection, Arduino also perform wireless communication with a pair of accelerometer sensor nodes attached on thigh and ankle to recognize the activity of a human subject.

Figure below showed the program code used to receive accelerometer data information from the two sensor node transmitters.

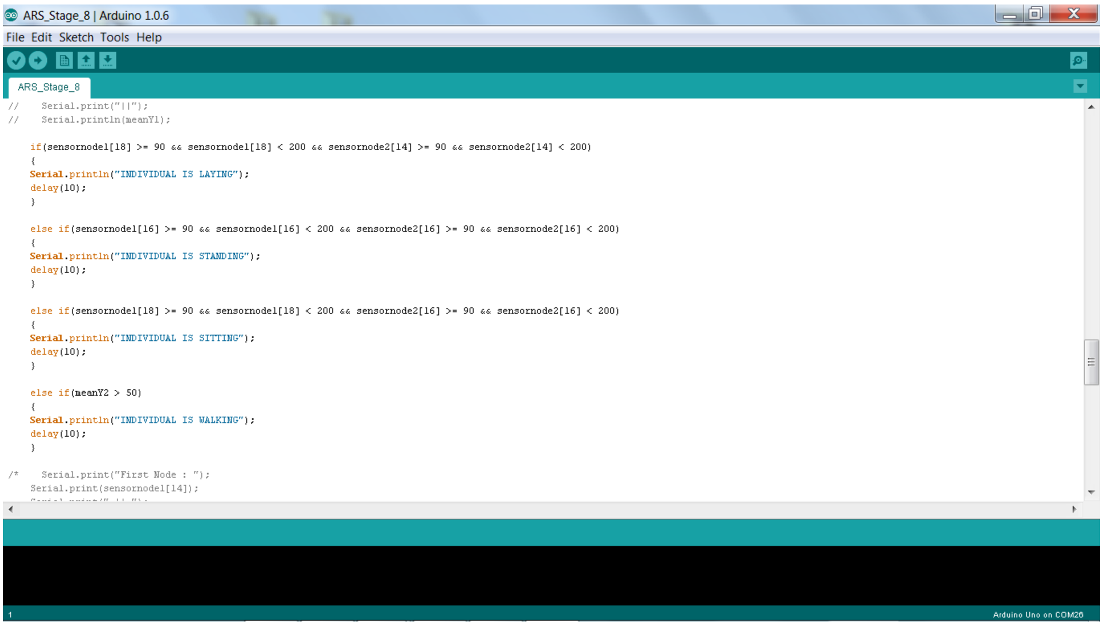

Figure 17: Arduino UNO Program Code for ARS Simulation

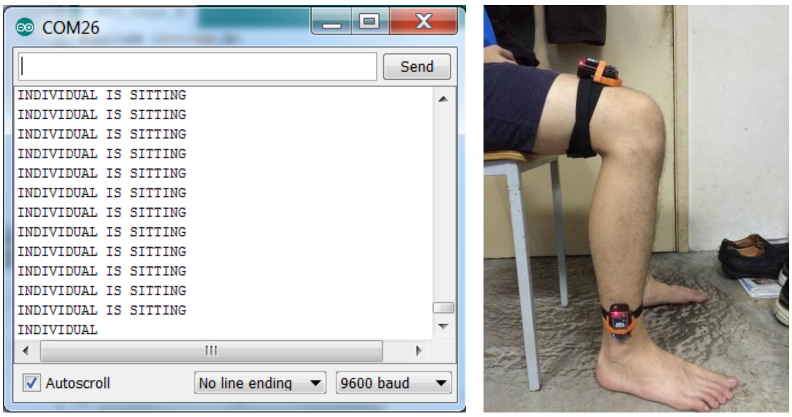

Figure 18: Individual is Sitting

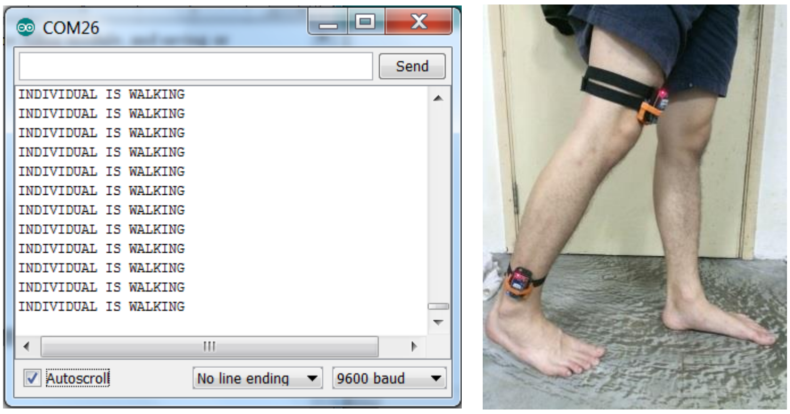

Figure 19: Individual is Walking

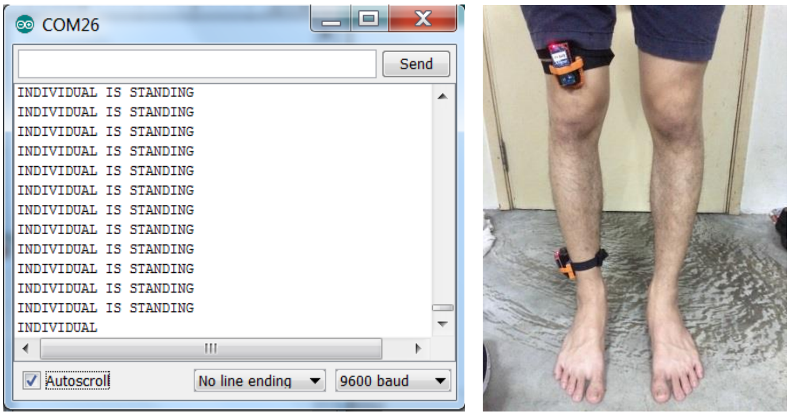

Figure 20: Individual is Standing

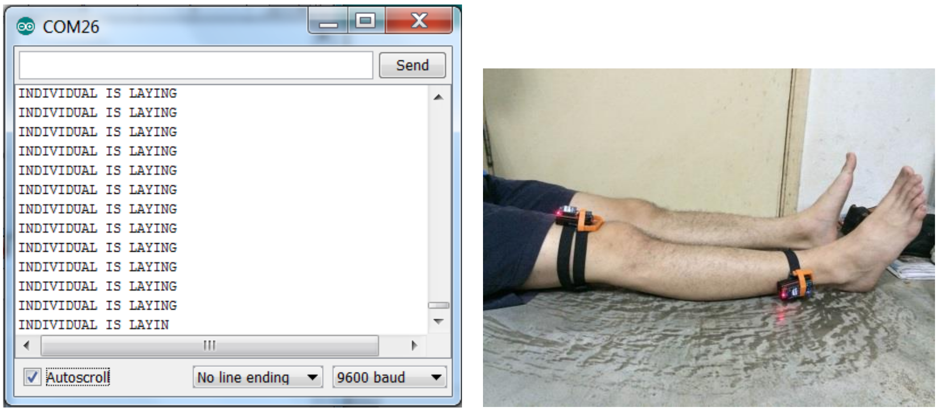

Figure 21: Individual is Laying

3.6 Key Milestone

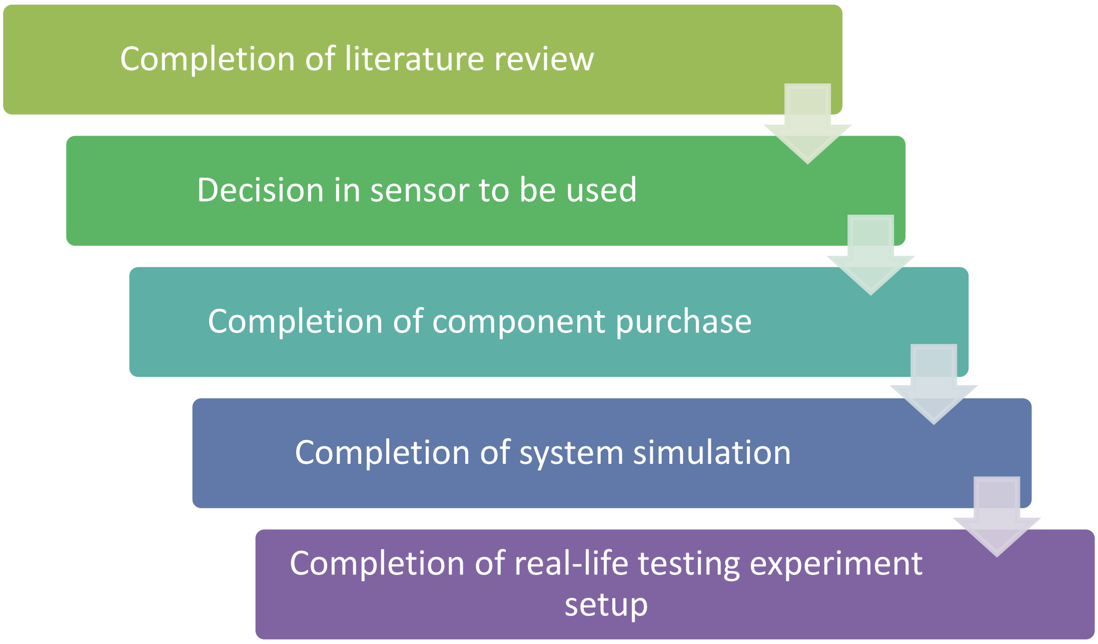

Figure 22: FYP Project Key Milestone

3.7 Gantt Chart

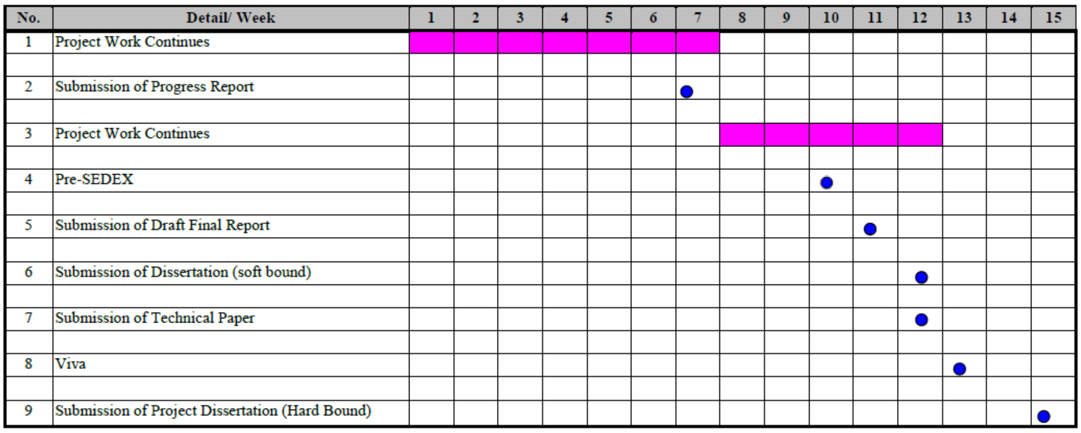

Figure 23: FYP Project Gantt Chart

CHAPTER 4: CONCLUSION AND RECOMMENDATION

4.1 Summary of Methodology

Throughout two semester of Final Year Project course, literature review on mental stress response, hardware implementation in GSR interface circuit, and raw signal filtering & smoothing is studied. The project had completed the real-life experiment setup test. Due to the various noises and unrelated signal that disrupting the raw GSR signal, sometimes the GSR sensor was difficult to receive the real arousal response from human subject and cause numbers of inaccurate result. The improvement in adding external factor sensors and several testing are suggested in order to obtain a useful signal from GSR sensor to develop a wearable stress sensory system with activity awareness system prototype.

4.2 Conclusion

In order to develop a wearable stress sensory system, portable, cost-effective and light-weighted device are essential factors in selection of components and detection system. Galvanic Skin Response (GSR) system acts as a suitable stress recognition system because of its simple and portable design by measuring skin conductance with only two electrodes.

With the achievement of 94.7% accuracy in activity recognition system, it is able to act as a data acquisition system to enhance the accuracy of stress monitoring result under severe human daily activities such as walking, standing, sitting and laying. Due to the demand of stress monitoring system, multi-parametric wearable stress monitoring device is trying to be develop in order the user to aware on own health condition and mental stress level.

For future work, Electrocardiography (ECG)[12, 22] is suggested to be implement which could help in improving the accuracy of GSR arousal response under various more kind of physical activities since that Heart Rate Variability (HRV) still remains as one of the dominant indicators for human stress compared to any other physiological signals.[23-27]

REFERENCES

[1] A. Sano and R. W. Picard, "Stress Recognition Using Wearable Sensors and Mobile Phones," in *Affective Computing and Intelligent Interaction (ACII), 2013 Humaine Association Conference on*, 2013, pp. 671-676.

[2] L. David and U. Mark, "Listen to Your Heart: Stress Prediction Using Consumer Heart Rate Sensors," ed, 2014.

[3] J. Wijsman, R. Vullers, S. Polito, C. Agell, J. Penders, and H. Hermens, "Towards Ambulatory Mental Stress Measurement from Physiological Parameters," in *Affective Computing and Intelligent Interaction (ACII), 2013 Humaine Association Conference on*, 2013, pp. 564-569.

[4] J. Wijsman, B. Grundlehner, L. Hao, H. Hermens, and J. Penders, "Towards mental stress detection using wearable physiological sensors," in *Engineering in Medicine and Biology Society,EMBC, 2011 Annual International Conference of the IEEE*, 2011, pp. 1798-1801.

[5] G. S. Everly and J. M. Lating, "The Anatomy and Physiology of the Human Stress Response," *A Clinical Guide to the Treatment of the Human Stress Response,* 2013.

[6] T. Hayashi, Y. Mizuno-Matsumoto, E. Okamoto, R. Ishii, S. Ukai, and K. Shinosaki, "Anterior brain activities related to emotional stress," in *Automation Congress, 2008. WAC 2008. World*, 2008, pp. 1-6.

[7] F.-T. Sun, C. Kuo, H.-T. Cheng, S. Buthpitiya, P. Collins, and M. Griss, "Activity-aware Mental Stress Detection Using Physiological Sensors," 2010.

[8] F. Alamudun, J. Choi, R. Gutierrez-Osuna, H. Khan, and B. Ahmed, "Removal of subject-dependent and activity-dependent variation in physiological measures of stress," in *Pervasive Computing Technologies for Healthcare (PervasiveHealth), 2012 6th International Conference on*, 2012, pp. 115-122.

[9] M. Delaney, "Managing Stress: A Team Approach."

[10] R. Kocielnik, N. Sidorova, F. M. Maggi, M. Ouwerkerk, and J. H. D. M. Westerink, "Smart Technologies for Long-Term Stress Monitoring at Work," 2013.

[11] P. Paoli, D. Merllie, and F. p. a. l. Millora, "Third European survey on working conditions 2000," *European Foundation for the Improvement of Living and Working Conditions,* 2001.

[12] Y. Okada, T. Y. Yoto, T. Suzuki, S. Sakuragawa, and T. Sugiura, "Wearable ECG recorder with acceleration sensors for monitoring daily stress: Office work simulation study," in *Engineering in Medicine and Biology Society (EMBC), 2013 35th Annual International Conference of the IEEE*, 2013, pp. 4718-4721.

[13] P. J. Rosch, "The Quandary of Job Stress Compensation," vol. 3, pp. 1-4, 2001.

[14] C. Jongyoon, B. Ahmed, and R. Gutierrez-Osuna, "Development and Evaluation of an Ambulatory Stress Monitor Based on Wearable Sensors," *Information Technology in Biomedicine, IEEE Transactions on,* vol. 16, pp. 279-286, 2012.

[15] J. Ogorevc, A. Podlesek, G. Gersak, and J. Drnovsek, "The effect of mental stress on psychophysiological parameters," in *Medical Measurements and Applications Proceedings (MeMeA), 2011 IEEE International Workshop on*, 2011, pp. 294-299.

[16] M. P. Tarvainen, A. S. Koistinen, M. Valkonen-Korhonen, J. Partanen, and P. A. Karjalainen, "Analysis of galvanic skin responses with principal components and clustering techniques," *Biomedical Engineering, IEEE Transactions on,* vol. 48, pp. 1071-1079, 2001.

[17] M. P. Tarvainen, P. A. Karjalainen, A. S. Koistinen, and M. V. Valkonen-Korhonen, "Principal component analysis of galvanic skin responses," in *Engineering in Medicine and Biology Society, 2000. Proceedings of the 22nd Annual International Conference of the IEEE*, 2000, pp. 3011-3014 vol.4.

[18] T. Westeyn, P. Presti, and T. Starner, "ActionGSR: A Combination Galvanic Skin Response-Accelerometer for Physiological Measurements in Active Environments," in *Wearable Computers, 2006 10th IEEE International Symposium on*, 2006, pp. 129-130.

[19] O. D. Lara and M. A. Labrador, "A Survey on Human Activity Recognition using Wearable Sensors," *Communications Surveys & Tutorials, IEEE,* vol. 15, pp. 1192-1209, 2013.

[20] C. Liming, J. Hoey, C. D. Nugent, D. J. Cook, and Y. Zhiwen, "Sensor-Based Activity Recognition," *Systems, Man, and Cybernetics, Part C: Applications and Reviews, IEEE Transactions on,* vol. 42, pp. 790-808, 2012.

[21] T. T. Boon, Y. L. Wee, and D. L. J. Hui, "Activity Awareness Can Improve Continuous Stress Detection in Galvanic Skin Response," *Proc. of IEEE Sensors,* November 2014.

[22] L. VOJTECH, R. BORTEL, M. NERUDA, and M. KOZAK, "Wearable Textile Electrodes for ECG Measurement," vol. 11, 2013.

[23] P. Karthikeyan, M. Murugappan, and S. Yaacob, "Multiple Physiological Signal-Based Human Stress Identification Using Non-Linear Classifiers," *ELEKTRONIKA IR ELEKTROTECHNIKA,* vol. 19, 2013.

[24] H. M. Tulen, P. Moleman, H. G. V. Steenist, and F. Boomsma, "Characterization of stress reactions to the stroop color word test," *Pharmacology Biochemistry & Behavior,* vol. 32, pp. 9-15, 1989.

[25] W. Linden, "What do arithmetic stresss measure? Protocal variation and cardiovascular response," *Psychophysiology,* vol. 28, pp. 91-102, 1991.

[26] J. A. Healey and R. W. Picard, "Detecting stress during real-world driving tasks using physiological sensors," *IEEE Trans. on Intelligent Transportation Systems,* vol. 6, 2005.

[27] J. Zhai and A. Barreto, "Stress detection in computer users based on digital signal processing of noninvasive physiological variables," *Proc. of 28th IEEE Anual Int. Conf. of Eng. in Medivine and Biology Society,* pp. 1335-1358, 2006.

APPENDICES

i) Arduino Program Code for Activity Aware Stress Sensory System

```
#include <Average.h>
#include <SoftwareSerial.h>
#define CNT 20
float buff[20];
int sensornode1[20];
int sensornode2[20];
float processedsensornode[3];
float processedsensornode1[3];
float processedsensornode2[3];
float storedValueX[20];
float storedValueY[20];
Average<float> valuex(10);
Average<float> valuey(10);
float minX1;
float meanX1;
float meanY2;
int tempo;
int i;
int counter = 0;

SoftwareSerial xBee(0, 1);

void setup()
{
  Serial.begin(9600);
  xBee.begin(9600);
}

void loop()
{
  Main:
  if(xBee.available())
  {
    tempo = xBee.read();
    if(tempo == 126)
    {
      i = 0;
      buff[0] = tempo;
//-------------------- read data --------------------//

    for(int j=1; j<20; j++)
    {
      buff[j] = xBee.read();
      if(buff[j] == 126)
      {goto Main;}
}
```

```
    }
    else
    {
      goto Main;
    }

//-------------------- data processing --------------------

    checkZero(buff);
    checkPolarity(buff);

//-------------------- check on the sensor node --------------------
    if(buff[4] == 86)
  {
    for(int k = 0; k < 20; k++)
    {
      sensornode1[k] = buff[k];
    }
  }
    else if(buff[4] == 87)
  {
    for(int k = 0; k < 20; k++)
    {
      sensornode2[k] = buff[k];
    }
  }

//-------------------- stored value for calculation --------------------

if(buff[4] == 87)
{
  storedValueX[counter] = sensornode2[14];
  valuex.push(storedValueX[counter]);
  valuex.get(counter);
  storedValueY[counter] = sensornode2[16];
  valuey.push(storedValueY[counter]);
  valuey.get(counter);
  meanY2 = valuey.stddev();
  counter++;
  if(counter == 10)
  counter = 0;
}

    if(sensornode1[18] >= 90 && sensornode1[18] < 200 && sensornode2[14] >=
90 && sensornode2[14] < 200)
    {
    Serial.println("INDIVIDUAL IS LAYING");
    delay(10);
    }
```

```
    else if(sensornode1[16] >= 90 && sensornode1[16] < 200 &&
sensornode2[16] >= 90 && sensornode2[16] < 200)
    {
    Serial.println("INDIVIDUAL IS STANDING");
    delay(10);
    }

    else if(sensornode1[18] >= 90 && sensornode1[18] < 200 &&
sensornode2[16] >= 90 && sensornode2[16] < 200)
    {
    Serial.println("INDIVIDUAL IS SITTING");
    delay(10);
    }

    else if(meanY2 > 50)
    {
    Serial.println("INDIVIDUAL IS WALKING");
    delay(10);
    }
  }
}

void checkZero (float buff[])
{
  if(buff[14] >= 235 || buff[14] <= 25)
  buff[14] = 0;
  if(buff[16] >= 235 || buff[16] <= 25)
  buff[16] = 0;
  if(buff[18] >= 235 || buff[18] <= 25)
  buff[18] = 0;
}

void checkPolarity (float buff[])
{
  if(buff[13] == 1)
  buff[14] = -buff[14];
  if(buff[15] == 1)
  buff[16] = -buff[16];
  if(buff[17] == 1)
  buff[18] = -buff[18];
}

void processdecimal (float buff[], float processedsensornode[])
{
  processedsensornode[0] = buff[14]/255;
  processedsensornode[1] = buff[16]/255;
  processedsensornode[2] = buff[18]/255;
}
```