BLOOD PRESSURE MONITORING SYSTEM

By

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17040

Dissertation submitted in partial fulfilment of
the requirement for the
Bachelor of Engineering (Hons)
(Electrical and Electronics)

JANUARY 2015

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
Electrical and Electronics Engineering Programme
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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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TUAN MOHAMAD AZLI BIN TUAN MOHAMAD AFFANDI

ABSTRACT

The project is named Blood Pressure (BP) Monitoring System. The expected results of this project are; to design and implement a reliable blood pressure measuring device and integrated with wireless technology for monitoring purpose. Author are required to build a device that measures blood pressure and transmit the readings wirelessly thus it can be displayed on the computer's screen. In 26 weeks' time, Author had successfully designed and implemented the circuitry of the system, and developed a coding to capture systolic and diastolic values. The project is fully completed and author managed to achieve all objectives where the BP measuring device is integrated with XBee Series 1 and able to transmit systolic and diastolic values to the computer wirelessly.

ACKNOWLEDGEMENT

Alhamdulillah, with the blessing from Allah SWT, I have successfully completed this Final Year Project with an expected results and outcomes. First of all, I would like to dedicate my highest thankful to both of my supervisor and co-supervisor, Dr. Hanita Binti Daud and Ir. Dr. Nursyarizal Bin Mohd Nor for the given opportunity to become one of their FYP candidates. In 26 weeks under their supervision, I have exposed to real problem solving situation and project management activity where it equipped me to improve my technical skills as well as management skills.

Apart from them, I would like give my appreciation to all the team members who also consistently gave me their supports and ideas throughout the period, especially to Nurul Fauzana Binti Imran Gulcharan, Siti Mariam Binti Mukhtar and Mohd Nur Fahmie Bin Rozli.

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LIST OF ABBREVIATION

BP	: Blood Pressure
EE	: Electrical & Electronics
FYP	: Final Year Project
kPa	: Kilo Pascal
mmHg	: millimetre of Mercury
PHP	: Hypertext Pre-processor
Psi	: Pound per Square Inch
USB	: Universal Serial Bus
UTP	: Universiti Teknologi Petronas
VB	: Virtual Basic

CHAPTER 1
INTRODUCTION

1.1 Background of Study

The purpose of designing and implementing blood pressure (BP) monitoring system is to ease the medical staff to monitor the BP of the patient. In normal wards, medical staff such as doctor or nurse, their practice of checking the patient’s BP is by going into manual measurement. This activity will be done frequently depend on the condition of the patient. In certain condition, they are required to measure the patient’s BP for every one hour in order to diagnose and ensure the patient’s BP is under control.

Using blood pressure monitoring system, patient’s BP condition can be measured without reaching their place to make the BP measurement. It also will acknowledge the nurse or doctor if there any abnormality of patient's BP thus will keep patient in good condition. They can easily monitor the patient's condition without wasting their time hence they can use their time for other important tasks. This system is capable to communicate with computers at 100 meters coverage. However, the coverage would require a communication repeater depend on location of both receiver (user) and transmitter (patient).

The patient's BP condition will be displayed on the computer's screen wirelessly. The user can set the frequency of checking for every 30mins for instance. Patient’s BP will be measured and sent it to the doctor's or nurse’s workstation through wireless communication medium (Xbee Series1).

1.2 Problem Statement

In general wards, patient's BP is measured manually where medical staff will take the measurement on every single patient at certain frequency. The required frequency of measurement is depending on the patient's condition and recommendation from doctor. This practice can be considered as poor in the following:

I. Medical staffs have to spend their time for the measurement where they have to walk to the patient's place from their work bench. This activity can cause the medical staff to have tough while working thus will result in lack of productivity in their working performance.
II. If the number of patient is huge and it will lead to insufficient of medical's staff capability to afford the frequent BP measurement.
III. In some cases, if the BP measurement is required for very four hours for instance, anything can happen within the four hours. By means BP level of patient possibly going to be too low (hypotension) or too high (hypertension). This will suffer the patient without any acknowledgement sends to the medical staff.

With the computerized BP monitoring system, above matters is possible to be reduced and ensure that the patient will always in alert of medical staff for any abnormality of their BP' status. The system can be implemented in the normal hospital or ward, where there are multiple patient need to be monitored at the same time.

1.3 Objective and Scope of Study

From the problem statements, author had come out with an idea to design and implement the blood pressure monitoring system. There are three objectives for this project as follows below:

1. To design and implement blood pressure (BP) measuring device.
2. To develop algorithm that can analyse pressure difference to come out with diastolic and systolic values.
3. To integrate blood pressure (BP) measuring device with wireless communication medium (Xbee Series 1).

1.4 Scope of Study

In order to achieve above objectives, there are three technical fields that involved in this project such as electronic device application, electrical power management, and sensor technology. The scopes of studies are:

1. Implementation of the algorithm and coding for pressure value analysis.
2. Implementation of the algorithm and coding for pressure sensor monitoring and DC Air Pump control.
3. Implementation of electrical and electronic circuitry covers integration, power management, and interface circuit.

CHAPTER 2
LITERATURE REVIEW AND THEORY

In this project, literature review is constructed to understand the related technology that had been used for blood pressure monitoring system. Since this project is the medical equipment, it is a must for author to have relevant readings not only on the technical part, but also medical papers which related to blood pressure. This topic is divided into two sections which are medical related papers and technical related papers.

2.1 Medical Papers

In this medical paper, author had divided into three sub-topics which are; definition of blood pressure, definition of blood pressure measurement, and classification of blood pressure values. Throughout on this sub-topic, reader is expected to understand; what blood pressure is, how frequent is blood pressure readings should be taken, how to take blood pressure measurement, where the best is spot to measure the blood pressure, and what the meaning of the blood pressure readings. Last but not list, author will discuss on what is the classification of blood pressure values based on age.

2.1.1 Definition of blood pressure

Blood pressure is the force of blood moving through our arteries as follows in FIGURE 1. These arteries are the blood vessels that flows the blood from our heart to our body [1]. It is important to check the blood pressure often because high blood pressure has no symptoms and it's considered as silent condition. If we do not acknowledge the high blood pressure for long time, it might damage our heart, stroke and other serious conditions. [2]. There are several factors that may cause the blood pressure measurement not accurate such as irregular heart rate, incorrect size of the cuff, the person is moving while taking the measurement, etc. [1] How often the blood pressure should be taken by the nurses is depending on the condition of the patient. For the patient who having stroke, the blood pressure should be taken more regularly compared to other patients. [3]

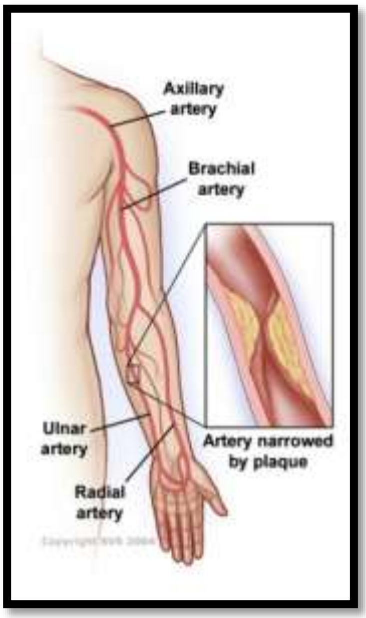


FIGURE 1. Arteries

2.1.2 Blood pressure measurement

There two values that describe the blood pressure measurement. These pressure values are return in millimetres of mercury (mmHg). The first value is called systolic which represent the pressure value of our arteries when our heart beats at the first time after compression. It normally will be displayed or written at upper readings. The second is called diastolic. It represents the pressure value in our arteries when the hearts start to rest where the last beat is occurred. These beats can be identified by the doctor using stethoscope while the pressure can be monitored using sphygmomanometer as follows FIGURE 2. [3]

FIGURE 2. Build-in stethoscope and sphygmomanometer

During the measurement, patient should be in the required position and condition. Thirty minute before taking the measurement, the patient should not smoke, having caffeine or exercise. The patient should sit down and relax for five minute before taking the measurement. The sphygmomanometer should be placed about same level with our heart's position purposely to avoid our reading to be affected by atmospheric pressure.

Lastly, the size of the cuff should suit the patient's upper arms. [4] There are three points that can use for measurement such as upper arm, wrist and finger. From among of medical researches, it is found that the best measurement is using upper arm. [5]. Thus, author had decided to implement the measuring device that measures at the upper arm instead of wrist and finger.

2.1.3 Classification of blood pressure readings

Blood pressure readings are varies by the time person wake up at the morning, during our lunch hour, asleep and others condition will influence our blood pressure readings. Most of the research stated that the best time for taking the measurement in the morning at least thirty minutes after our meal.

In order to ensure the result is validated, the frequent readings should be taken at the same time on the next day. [6] The ideal readings for various age and different genre are not the same. Most of the medical associations had posted the standards of the readings respect to each class of ages and genre as follows TABLE 1. [7].

TABLE 1. Blood pressure ideal reading according to age

Age	Range	Median Normal Systolic/Diastolic (mmHg)
15 to 19	Minimum	105/73
	Average	117/77
	Maximum	120/81
20 to 24	Minimum	108/75
	Average	120/79
	Maximum	132/83
25 to 29	Minimum	109/76
	Average	121/80
	Maximum	133/84
30 to 34	Minimum	110/77
	Average	122/81
	Maximum	134/85
35 to 39	Minimum	111/78
	Average	123/82
	Maximum	135/86
40 to 44	Minimum	122/79
	Average	125/83
	Maximum	137/87
45 to 49	Minimum	115/80
	Average	127/84
	Maximum	139/88
50 to 54	Minimum	116/81
	Average	129/85
	Maximum	142/89

2.2 Technical Papers

In technical paper, author has described a useful resource that obtained from several related technical papers. There are two sub-topics under these technical papers which are electronics blood pressure monitor, wireless technology and ZigBee. In this topic, reader is expected to expose on how the electronics blood pressure monitor works and what is the possible wireless technique to use for this project.

2.2.1 Electronics blood pressure monitoring.

Now days, quite number of electronics blood pressure monitor are manufactured for utilization in hospital and home as medical device. There are several manufacturers that produce this device. For instance is OMRON, where their product is the best sells for electronics blood pressure monitoring. Normally, in the current market, there are two type of electronics blood pressure monitoring whether it can be measure on personnel's wrist or upper arm. From author's readings, it found that the device measures on the upper arm are more accurate and reliable compared to the forearm or wrist spot. [8].Most of these electronics device is based on non-invasive oscillometric method. By this method, it required inflated upper arm cuff that can provide stable readings of pulsation that generated by our artery's wall. This pulsation value is detected using pressure sensor that will be interpreted and converted to blood pressure value. [9]

This electronics device is automated device that operates two basic steps in taking measurement for blood pressure which are systolic and diastolic readings. First of all, the pump will pressurize the cuff while the pressure in measured by the pressure sensor. This pressurize mode will continue until the pressure sensor stop receiving pulsation from the artery. This means the blood is no longer flows in the artery. At the same time, the air is slowly released through the small outlet from the tubing. The pressure sensor will detect the first vibration of the cuff; this will be interpreted as systolic reading. While the pressure is continuously decreasing, the amplitude of the cuff will slowly decrease due to the flow rate of the blood is decrease. The pressure sensor will keep measuring the vibration until the difference amplitude is almost zero; this value will be interpreted as diastolic reading. Both systolic and diastolic readings will be displayed on the screen for record keeping and interpretation by medical personnel. [9] FIGURE 3 shows the typical data that obtained during the measurement.

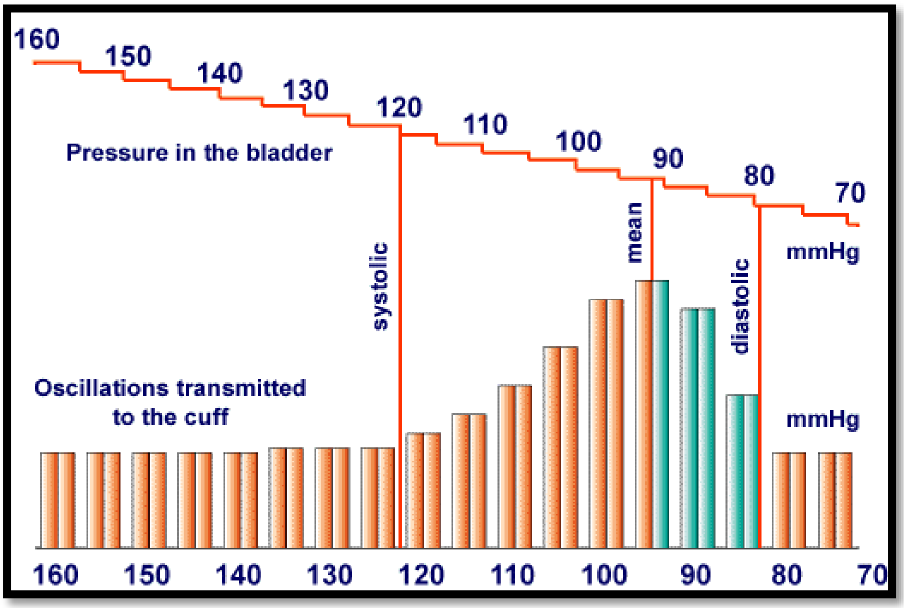


FIGURE 3. Blood Pressure reading using oscillometric technique

The other technique is using Pulse Time Technique (PTT), where it is an introduction to the design of a cuff-less blood pressure monitoring. There are two types of pulse waves which usually paired. PTT means the different between two pulse waves that propagates at the same cardiac cycle from both different arterial spot. This technique can provide a continuous monitoring/reading of systolic and diastolic values. [15]. However, author had decided to implement the BP measuring device using oscillometric technique instead, because PTT seems to be more sophisticated and complex in signal processing and data analysis.

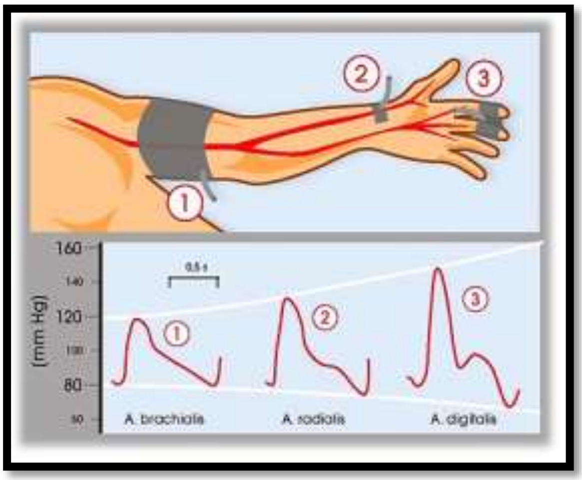


FIGURE 4. Typical reading for PTT technique

From recent collected info, author had briefly understood what is the tubing mechanism, components and hardware is used to build the device. Those identified components are; upper arm cuff, costume tubing, pressure release valve, pressure sensor, air pump, microcontroller and display device.

2.2.2 Wireless technology

The purpose of using the communication medium is; to enable the BP monitoring activity can be done remotely using computer as an interface to the user. It is expected to have only one way communications where the user can receive the data from the device periodically (minimum every 30miutes). This application will be applied to a group of patients where the blood pressure data need to be specified to indicate the patient individually.

Through the research, author had found that Radio Frequency Identification (RFID) is considered suitable device to be implemented in this system. It can allow the system to recognize which blood pressure value refers to which patient. There have two types of RFID which are passive RFID and active RFID. The main different between active and passive RFID tag is; both device have a different type of power source. Active RFID tag required internal power source while the passive RFID tag need to have an external source or called RFID reader. On top of the power source, the communication range between active and passive RFID are differ where the active RFID provide better communication range. Therefore, active RFID tag most likely suitable for this application as compared to passive RFID. [16] However, the use of active RFID tag is limited to certain period of time because it use internal power that need to be recharged or replaced like battery for instance. This may leads to inaccurate reading received by the user when voltage level from the internal power falls below the normal operating limit. [17]

Instead of using RFID tag, author had found that the most recent and suitable wireless medium is ZigBee. This is also a wireless technology where it used to allow a computer to share information in two way communication and it employs the use of wireless personal area network WPAN. It has simple and low power consumption thus it is very suitable for this project. Plus, ZigBee is compatible with Arduino board, and can be easily configured and reliable. [18]

2.2.3 Wireless technology in BP measuring system

There are several wireless devices that established now days. This technology had now invented for health monitoring system application. One of the examples is the device that produces by Wun-Jin Li, Yuan-Long Luo, Yao-Shun Chang, and Yuan-Hsiang Lin (2010) where they had successfully implemented the blood pressure monitoring system. The system comprises of BP monitor for measurement and computer for result display. They used ZigBee wireless device as communication medium in order to enable the data to be sent to the computer thus it will display real-time BP status of the patient. [11]

On the other research application which related to wireless technology, is the system that made by Bonifacio Castano and Maria Rodriguez-Moreno (2011). They use a hybrid wireless system by integrate ZigBee and RFID. This system is use to monitor the personnel’s position and movement on specific area. RFID is used to locate the exact position of the personnel while the ZigBee is utilized to transmit all the required data to the display facility. [12]

Author had proposed to use Arduino Uno as controller because it's reliable, simple and easy to develop coding and algorithm. This microcontroller is well-known controller and capable to controls simple mechanism such blood pressure device. From the other sources, it found that there are often for the researchers used ZigBee wireless device as the communication medium. In addition, it is most compatible with arduino microcontroller which can ease author to develop the coding and integration. Thus, for this project, author had proposed to use ZigBee (Xbee Series 1) as the communication medium.

2.2.4 ZigBee Technology

ZigBee is the communication device that is manufactured by ZigBee Alliance. ZigBee Alliance had produced this compatible and simple electronic communication for consumers in various fields. It is widely used for various wireless applications. Its design is known as personal area network (WPAN) standard and listed under IEEE 802.15.4 protocol. Apparently, the typical ZigBee works with frequency bands of 2.4GHz and it provides 250kbps as a transmission rate for fast and reliable application which compatible with many electronics devices [13]. Below is the comparison between ZigBee and other wireless devices [14].

TABLE 2. Comparison between ZigBee and other communication device

Market Name / Standard	**ZigBee**	**Wi-Fi**	**Bluetooth**
Application Focus	Monitoring and Control	Web, Email, Video	Cable replacement
System Resource	4KB – 32KB	1MB+	250KB
Battery Life(days)	100 – 1000+	0.5 - 5	1 – 7
Bandwidth(KB/s)	20 - 250	11000+	720
Transmission Range	1 – 100+ m	1 - 100	1 – 10+
Success Metrics	Reliability, Power, Cost	Speed, Flexibility	Cost, convenience

From the comparison, its shows that ZigBee is the most suitable for this project as the application are focused on monitoring and control system. In fact, it is also required a very small electrical power thus will provide better battery lifespan and power consumption. Last but not list, its transmission range is suitable as the normal hospital facility is ranged less than 100meters. [14]

CHAPTER 3
METHODOLOGY AND PROJECT WORK

In this chapter, author had divided the methodology into three sub-topics which are **research methodology, detailed research methodology, Gantt-chart and miles stone, and tools.** Throughout this chapter, it describe on how this research is done, and what are the materials used throughout completion of the project. Furthermore, author also had discussed about the **algorithm of the measuring device, system architecture, detail of the design circuitry**, and **implementation of communication medium.**

3.1 Research Methodology

In this sub-topic, it provides the overall flow diagram of the research methodology of this project. FIGURE 3 shows the overall flow diagram of the research methodology flow. It shows the expected progress and actual progress of this project towards the end of completion.

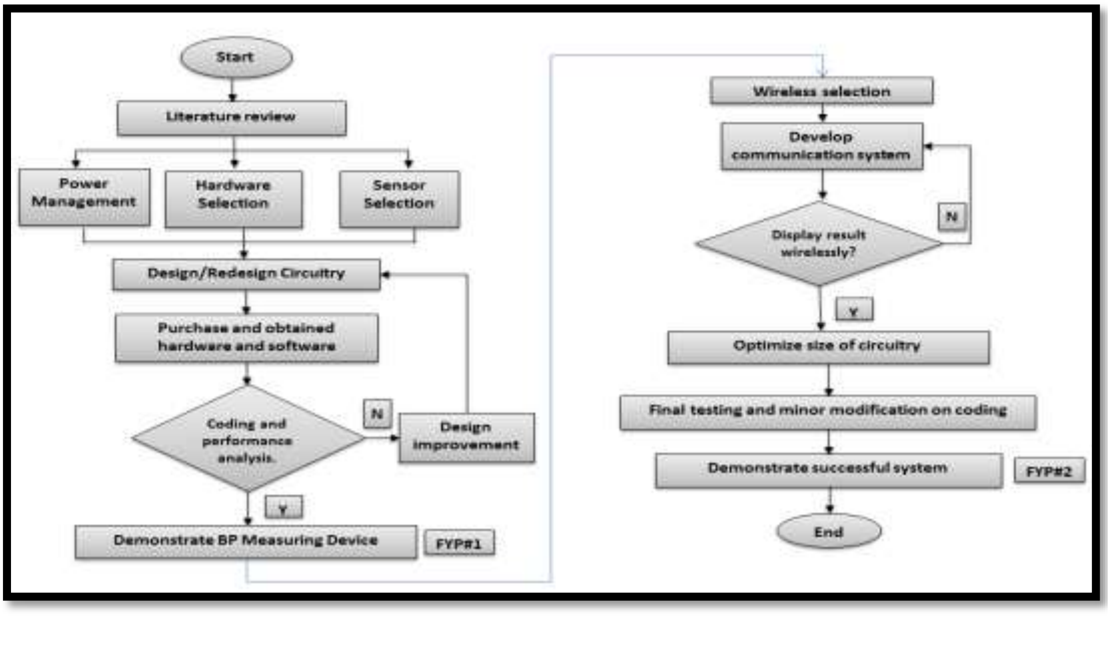


FIGURE 5. Research Methodology

3.2 Detailed Research Methodology

FIGURE 6 shows brief description of the research methodology. It consists of carried out activity throughout FYP1 and FYP2. All the actual activity is in line with the plan activity excluding the development of the coding where the author had carried out the coding beyond the expected timeframe. However, author managed to complete the project within the time frame.

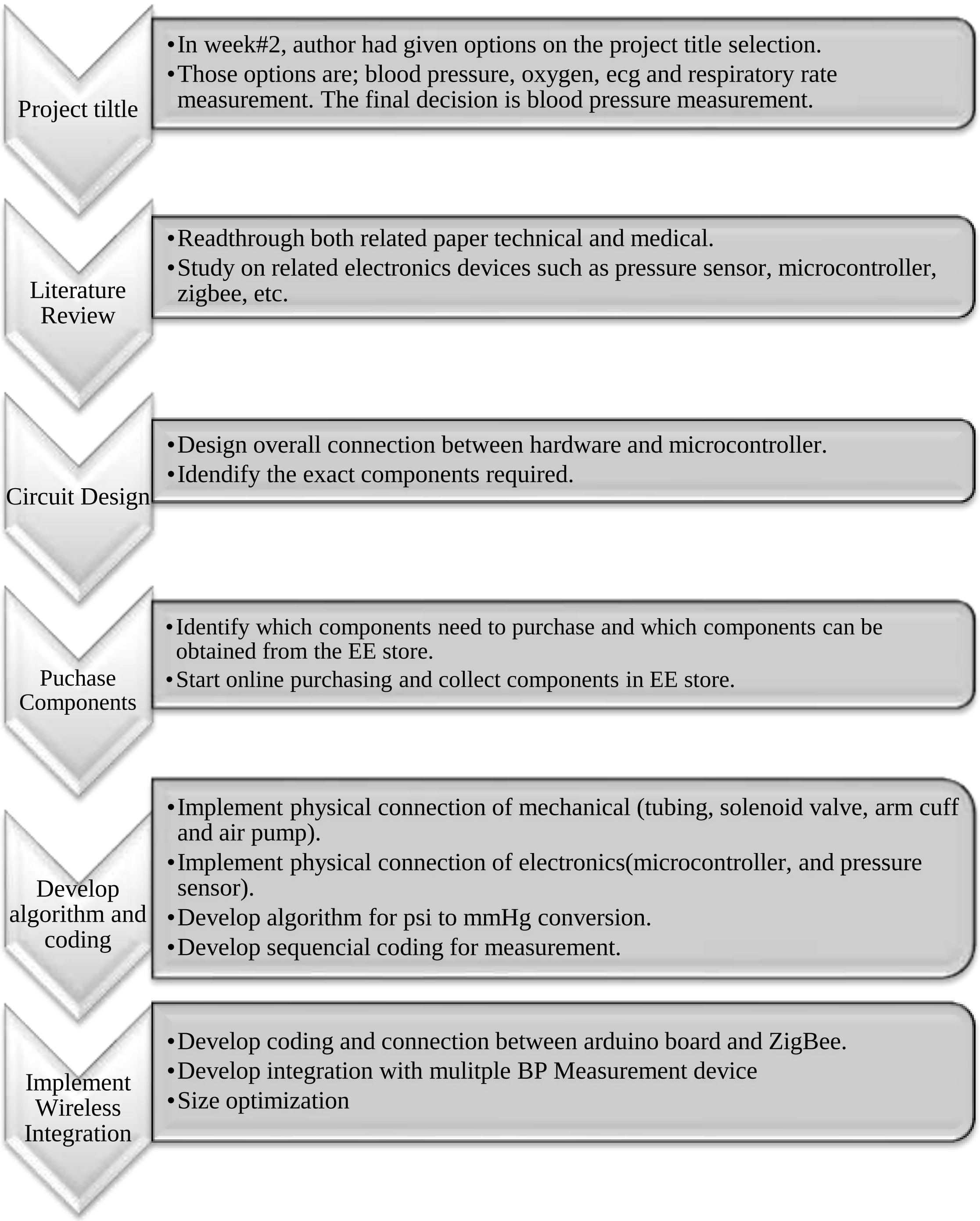


FIGURE 6. Research Methodology

3.3 Gantt-Chart and Milestone

Author had decided to combine both Gantt-chart and milestone of the project. This will provide better understanding on the project timeline from the project title selection until end of FYP2. For FYP1 period, author is expected to come out with successful measuring device which provide local display. As such, fabrication and wireless integration will be developed and implemented during FYP2. Following TABLE 3 shows the combination of both Gantt-Chart and Milestone of the research.

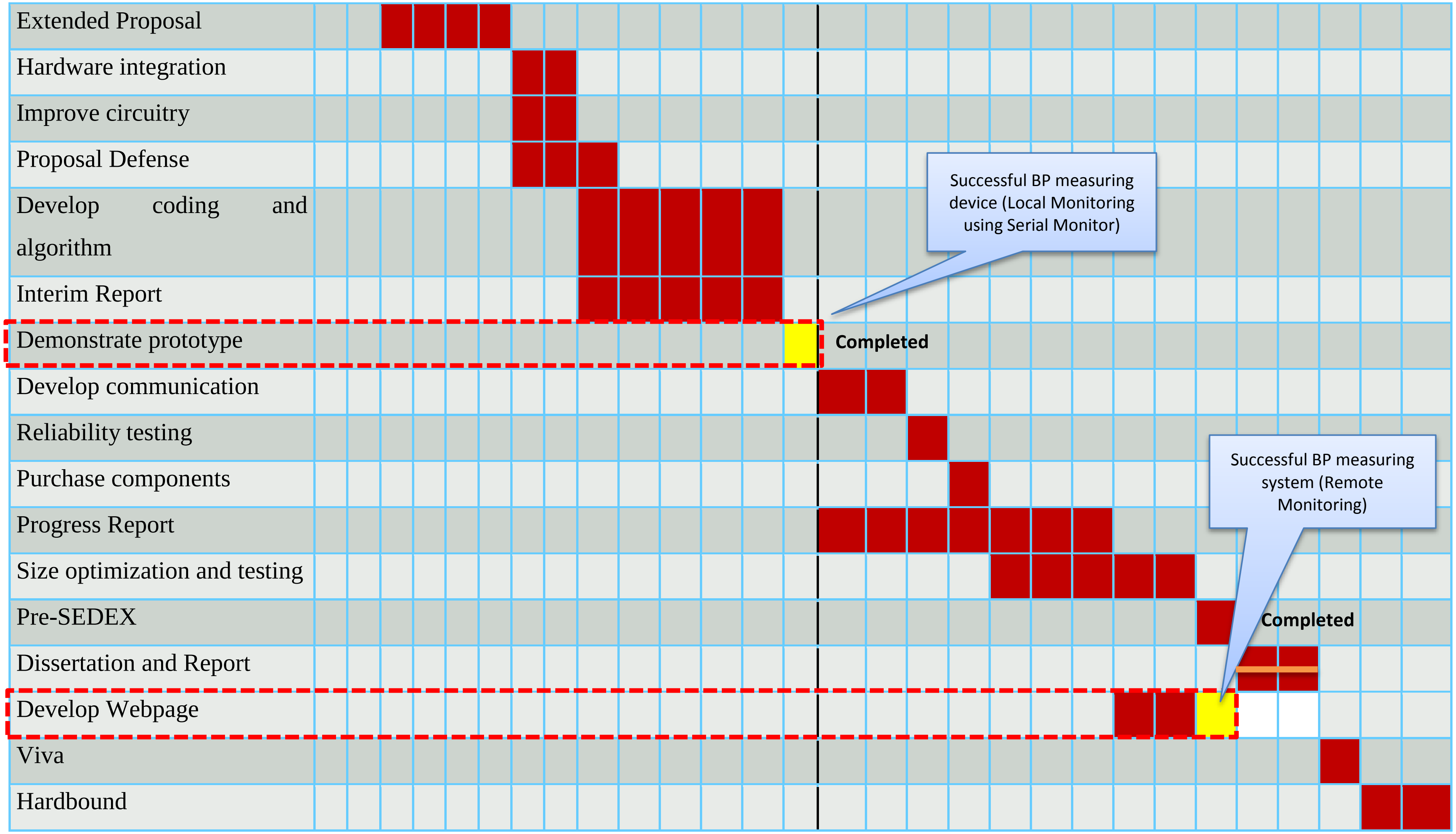
TABLE 3. Gantt-chart and Milestone

Week / Activity	Week (FYP1)														Week (FYP2)														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Literature Review																													
Propose title																													
Develop product spec.																													
Hardware analysis(suitability)																													
Power Management analysis																													
Design circuitry																													
Purchase components																													

Progress

Plan

Milestone


Extended Proposal
Hardware integration
Improve circuitry
Proposal Defense
Develop coding and algorithm
Interim Report
Demonstrate prototype
Develop communication
Reliability testing
Purchase components
Progress Report
Size optimization and testing
Pre-SEDEX
Dissertation and Report
Develop Webpage
Viva
Hardbound
Successful BP measuring device (Local Monitoring using Serial Monitor)
Completed
Successful BP measuring system (Remote Monitoring)
Completed

3.4 Tools

In this sub-topic, the required material divided into two which are hardware and software. TABLE 4 provides list of the required hardware and software. Some of the hardware is not available in UTP store which requires online purchasing. For your information, author had obtained all the components and successfully implements it including the wireless medium. The circuitry is working very well and meeting the expectation.

TABLE 4. Required Materials

Materials	Description	Brand
Hardware Components		
Breadboard	Temporary base for circuitry	N/A
Multimeter	To check connectivity, current and voltage	N/A
Electronics BP Monitor	To validate result of the product	HEM 7120
9V rechargeable battery	To power up whole electronics device.	Energizer
Pressure Sensor	To detect the pressure status of the cuff	HSCDRNN400MGAA5
Solenoid Valve	To release pressure inside the cuff after measurement is done	SC0526GB
Arduino, UNO	To receive signal from input device and reacts to manipulate output devices.	N/A
Software		
Eagle	To draw circuitry for board fabrication	N/A
Arduino Programmer	To write, compile and upload coding	N/A
PSpice	To design and simulate the circuitry	N/A

In this sub-topic, author also has provided the description for the four main hardware components that had been utilized for the measuring device. There are Honeywell Pressure Sensor, DC Air Pump Motor, DC Solenoid Valve and Arduino UNO mictrocontroller.

3.4.1 Pressure Sensor

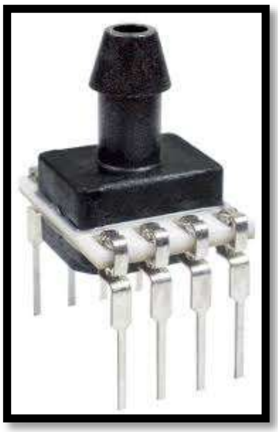


FIGURE 7. Honeywell Pressure Sensor

This sensor is the most crucial component of this project. Author had spent about a month to study and make the selection for this sensor. The selection of the sensor will determine the resolution of the reading from the sensor. The purpose of selection of the sensor is mainly to ensure that the selection is not over design or under design from the required operating range. Although over design will not cause the sensor to damage, however it will result in higher resolution thus will result inaccurate reading. For this project, it required to have a pressure sensor that has range from 0mmHg to 200mmHg. Throughout the research, author had found the suitable sensor where it provides 0psi to 5 psi ranges which equivalent to 0mmHg to 254mmHg. The output is return as voltage which ranged from 0V to 5V ±%5 accuracy. It utilized piezoresistive transducer which is constructed in a diaphragm form. The diaphragm will stretch when there is difference pressure and will introduce an electrical signal (voltage) [19].

Based on the experimentation of the sensor, author had found that the signal from the sensor is fluctuated very high during the compression stage. As a solution, author had decided to employ a low-pass filter circuit which can provide 10 Hz in frequency. It utilized simple filter circuit by connecting series of resistor and capacitor parallel with the sensor's output. The filtered signal will be detected and analysed by the Ardunio UNO microcontroller.

3.4.2 Microcontroller

FIGURE 8. Ardunio UNO

In this project, author had decided to use Arduino UNO as controller. It utilized an Atmega328 microcontroller that has 14 digital pins, 6 pins. Among 14 digital pins, there are 6 of them which provide PWM outputs. The project used this PWM output for motor control. One of the analogue pin is connected to sensor's output to retrieve the analogue value. It has built-in ADC components where it will provide an analogue signal to digital signal in 8-bit weight which range from 0 to 1023[20]. From the digital range that provided by the controller, the resolution of the sensor that will be analysed by the microcontroller as follows.

Resolution = (254mmHg-0mmHg)/1023

= 0.248mmHg

Based on the obtained resolution, the author had concluded that the selected sensor that embedded with this Arduino is capable to analyse the beats. This is because the typical beats are normally gives 3-5mmHg of amplitude.

3.4.3 Pump and Solenoid Valve

FIGURE 9. Pump and Solenoid Valve

The selection of the pump and valve is also considered as crucial part because it required to have a component that consume low power and small in size. Author had decided to use only 9V battery as main and single power supply for all the components inside the measuring device. Through the research and readings, author had found the suitable pump and valve as follows FIGURE 9. Both selected components are satisfies the requirement in term of size and power consumption. It operates at 5VDC and sinking current at maximum 500mA only.

As mentioned before, the pump is used to compress the arm cuff at the first stage of measurement and valve is used to keep the pressure trapped inside the tube and arm cuff during the pressure and beats being analysed by the controller. The valve will be deactivated once the measurement is done. The valve will release the compressed air inside the tube and arm cuff.

3.5 Algorithm

The system will start by pressing Push Button (manual mode). Alternatively, it can be operated for every 30, 60, 90, and 120 minutes (auto mode). This time interval is determined by using four DIP switches that available at the measuring device. The user has to turn ON switch 1 to operate it for every 30minutes, or turn ON switch 2 for 60 minutes and so on.

The measuring is starts by compressing patient's upper arm using DC Air Pump and the air will be trapped using Electrical Solenoid Valve. Beats at the patient's artery will introduce back pressure in the tube. The pressure will be detected by pressure sensor and the beats will be analysed by the controller. Pump will stop compressing the arm cuff when the back pressure is almost zero which means there is not beat occur at the artery (no blood flow). When pump stops, the pressure inside the cuff will be decreased due to the air leakage from the leakage port as shown in FIGURE 10. It will continue to decrease until the blood starts to flow.

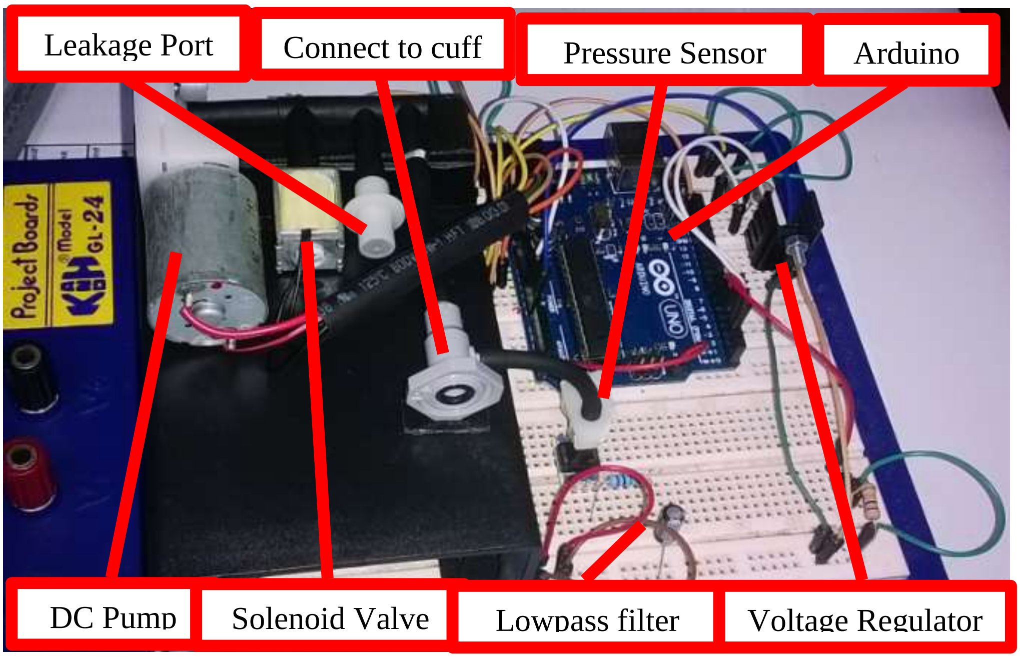


FIGURE 10. Actual implementation

During the first blood flow, the sensor will detect and controller will record the present pressure value where it is called systolic value. At the same time, depressurize still continue while the controller is keep analysing the beats until the beats is no longer existed which means blood flow is now flowing in normal amplitude and relief. Again, controller will record the pressure during the last beats of the artery and this pressure is called diastolic value. Once the controller recorded these systolic and diastolic values, the solenoid valve will be deactivated and the pressure inside the arm cuff is released. FIGURE 11 is used to illustrate on how the measuring device is working. This is also can be regarded as the entire algorithm for the measuring device.

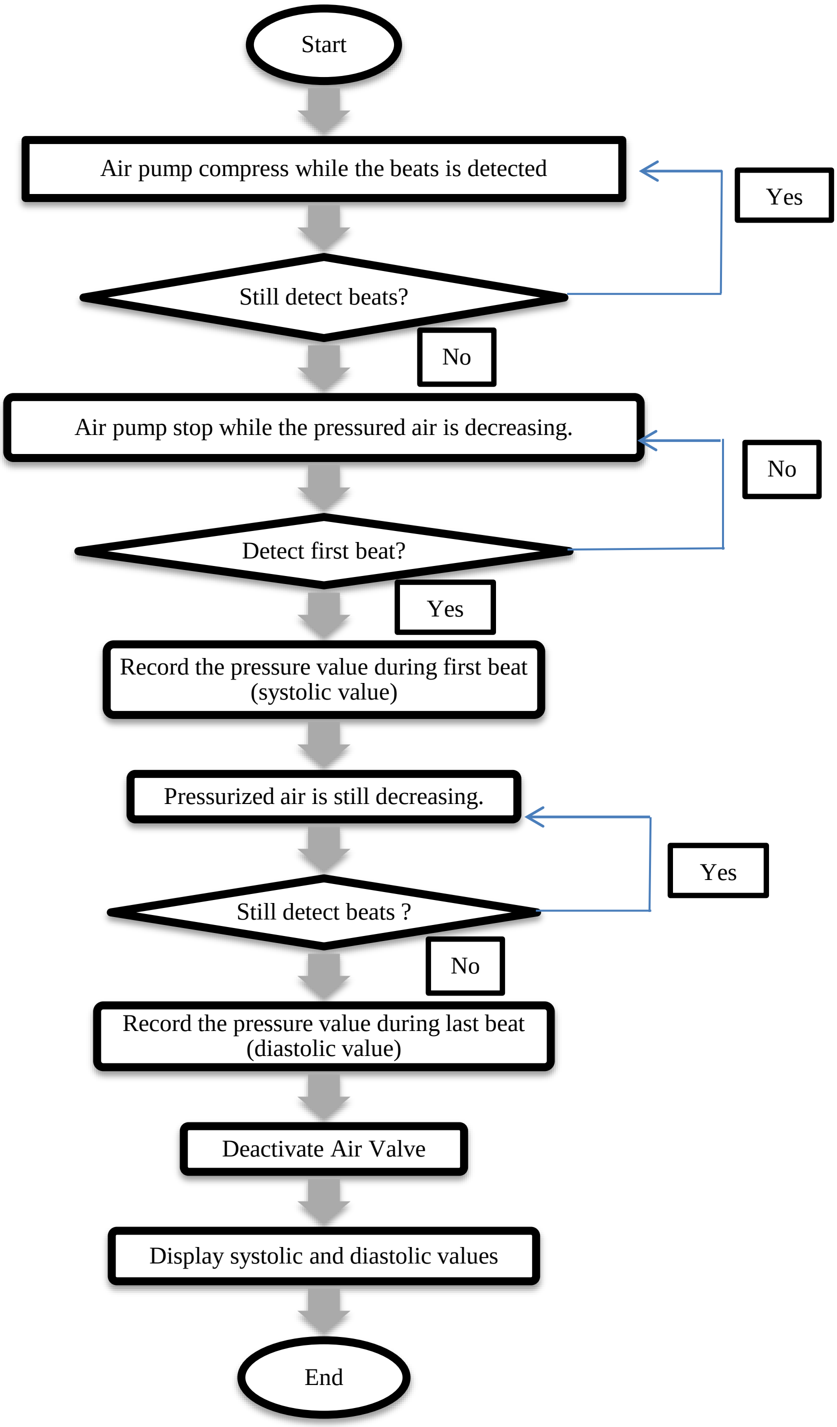


FIGURE 11. Measuring Operation (Algorithm)

3.6 System Architecture

In this sub-topic, the discussions are covered on power management, and overall circuitry. Author had constructed system architecture to describe the overall of the system as follows FIGURE 12. This diagram shows the connection of all components.

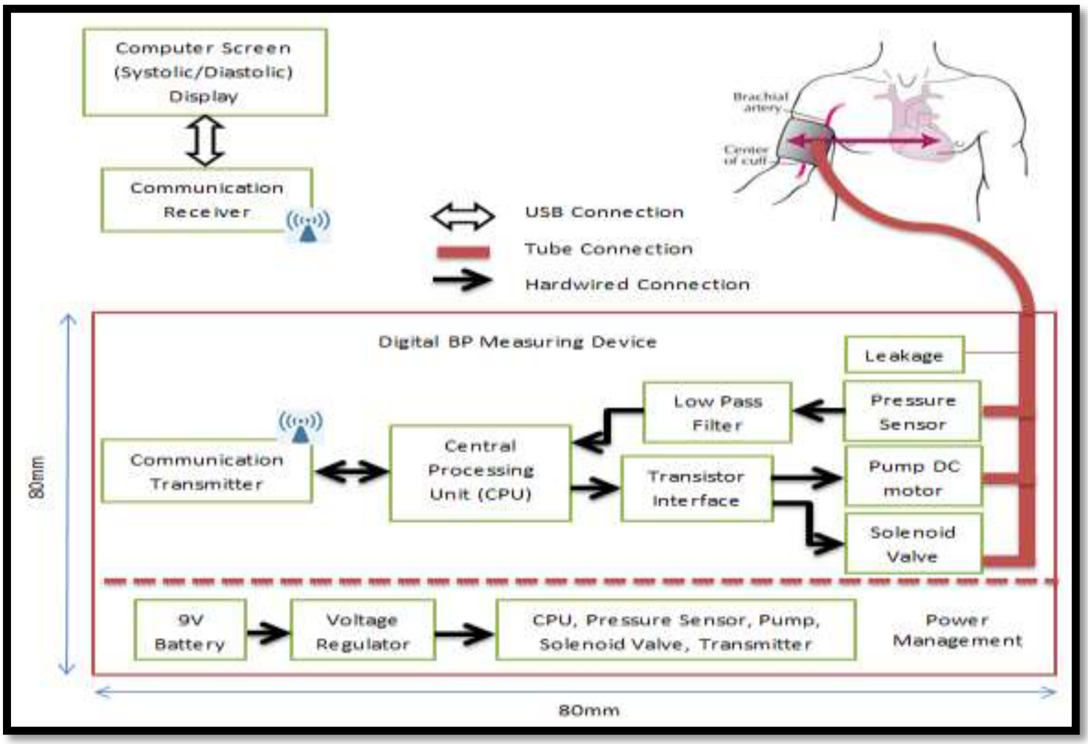


FIGURE 12. System Architecture

During the design stage, author had a concern on the power management. In order to build a device that is wearable, it has to be compact in size which required to use components that consume less power thus low power source is needed. Throughout the research, author had proposed to use a 9V battery as a main supply for the device. From the implementation, it shows that this battery is capable to supply and sustain all the components. More importantly, 9V-5V voltage regulator provides a stable and very less ripple voltage output. This is very suitable to use as supply voltage to the pressure sensor because this sensor requires a stable supply voltage. The analogue output from the sensor is dependent on the Voltage supply as follows datasheet in FIGURE 13. However, the battery has its own current capacity and the voltage will deplete once the stored current is at very low level, thus the battery needs to be replaced or recharged.

Sensors are either 3.3 Vdc or 5.0 Vdc based on listing selected				
Supply current:				
3.3 Vdc supply	-	1.6	2.1	mA
5.0 Vdc supply	-	2	3	
Compensated temperature range[4]	0 [32]	-	50 [122]	°C [°F]
Operating temperature range[5]	-20 [-4]	-	85 [185]	°C [°F]
Startup time (power up to data ready)	-	-	5	ms
Response time	-	1	-	ms
Upper output clipping limit	-	-	97.5	%V_{supply}
Lower output clipping limit	2.5	-	-	%V_{supply}
Accuracy[6]	-	-	±0.25	%FSS BFSL
Total error band[7]	-	-	±1	%FSS[3]
Output resolution	0.03	-	-	%FSS[3]

FIGURE 13. Sensor's datasheet

Author managed to integrates all input and output devices which comprises of pressure sensor, switches, solenoid valve and pump with controller (Arduino Uno board) as follows FIGURE 14. The device is integrated with Xbee Series 1 module and able to display to reading locally (Arduino's serial monitor) and wirelessly (Xbee's X-CTU window).

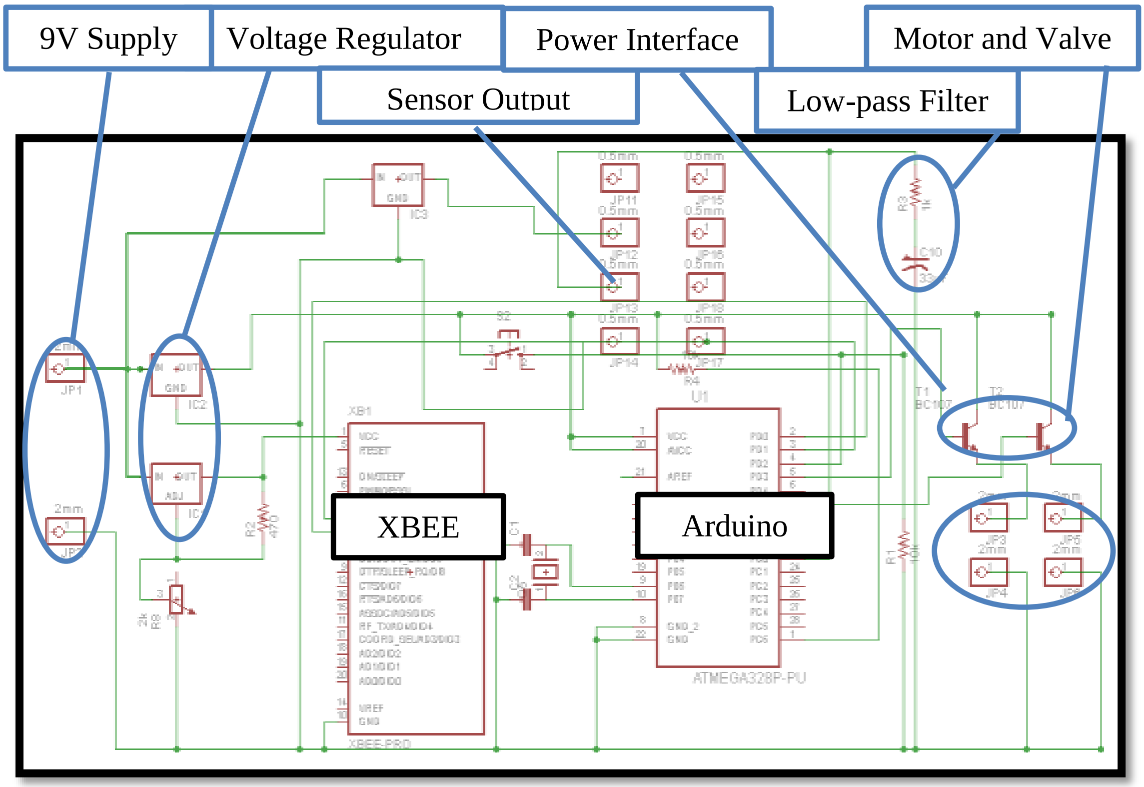


FIGURE 14. Circuitry

3.7 Implementation of Xbee

After the measuring device was successfully tasted and implemented, author have proceed on minimizing and rearranging the connection and components of the device for size optimization and easy troubleshooting purposes. The circuit that have been optimized as follows in FIGURE 15 where all the components are placed below the black box except for pump and valve. For the Xbee transmitter, both of its Tx and Rx pins are connected to the Rx and Tx pins of the Arduino. On the receiver side, the Xbee module is connected to the user PC via USB cable which will be act as receiver node.

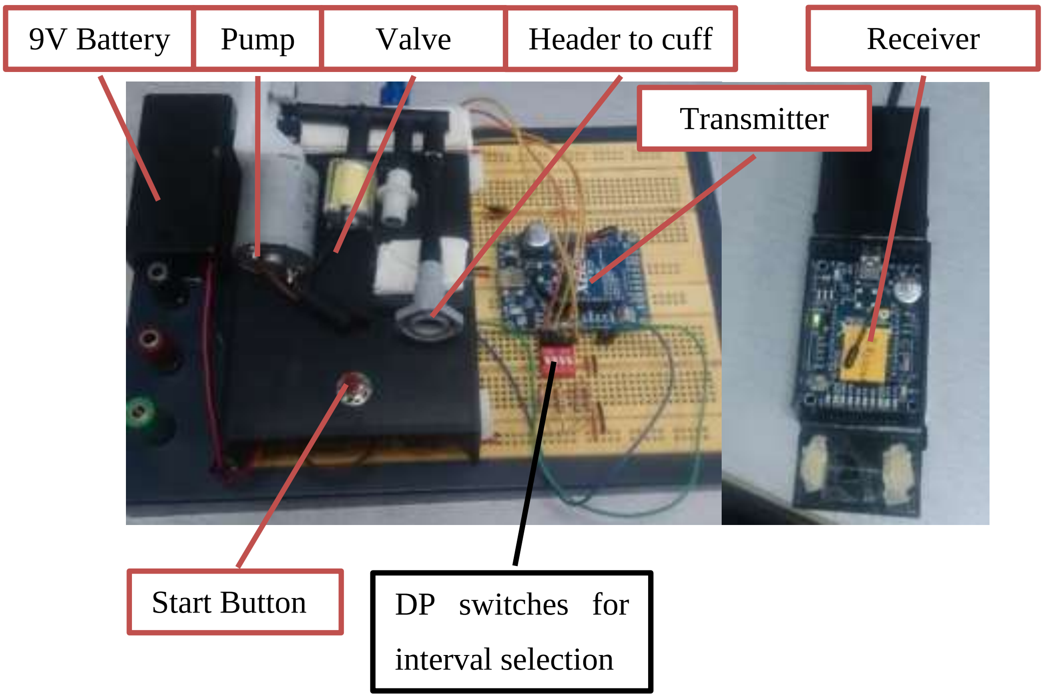


FIGURE 15. BP measuring device integrated with Xbee.

The measuring device can be operated manually and automatically. For the manual mode, user needs to press start button without making any selection for time interval. Measuring will immediately starts and then the controller will send the readings to the receiver once the signal analysis is done by the controller. Typically, one measurement will take about 30 to 40 seconds to compress, analyse, and send the values. If there any selection at DP switch is made, the measuring device will operate automatically depends on the selected interval. This selection is done using four DP switches to determine the interval is 30, 60, 90 or 120 minutes. The controller will disregard the interval (auto mode) if there are more than one DP switch is turned ON.

For the communication medium, author had tested the transmission signals from device to user for several times and it found that the Xbee Series 1 gives reliable communication and easy to configure. FIGURE 16 shows the results that have been displayed wirelessly to user's computer (X-CTU, receiver) and the local display using serial monitor. X-CTU software is used to display the data that received by the Xbee Series 1 receiver. This receiver will be connected through the universal serial bus (USB) of the user's computer. The received data from transmitter (BP measuring device) will be displayed through this software. It is an open-source configuration and free for X-bee users. It is considered as simple-to-use graphical interface where it has been utilized by many developers especially in Radio Frequency application project. This software is being updated from time to time which provide tools that ease developers to setup, configure and test the receiver.

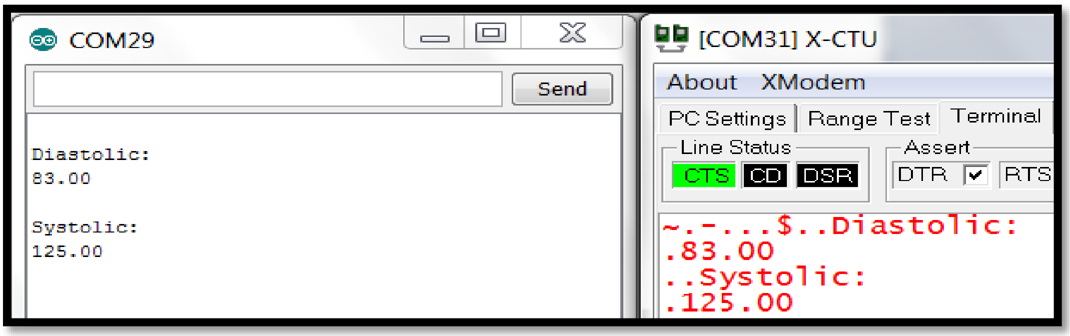


FIGURE 16. Local and remote display.

3.8 Interface Design (Webpage)

Even though the device is successfully integrated with Xbee Series 1, the value that displayed through X-CTU software is not organized and not friendly user for medical staff to utilize it. Therefore, author had decided to use an interface software to enable the received data through X-CTU can be display properly and well organized. The software called Visual Basic (VB). By using VB software, it allows developer to design the interface window in their own way. Using this approach, the retrieved data from BP measuring device can be interconnected with the web application thus the values can be displayed globally through internet.

As such, with the knowledge and understanding on web application design using Hypertext Pre-processor (PHP) language, author had come out with a new designed webpage design. This designed webpage is use to enable the received data from measuring device to be displayed globally. This webpage are developed with to provide following features:

I. Login User Name and Password (Safety purpose, only dedicated personnel can access the system)

FIGURE 17. Login Page

II. Home page (List all the patient's ID that equipped with BP measuring device)

FIGURE 18. List of Patient

III. Individual Status (Latest systolic and diastolic value of the patient)

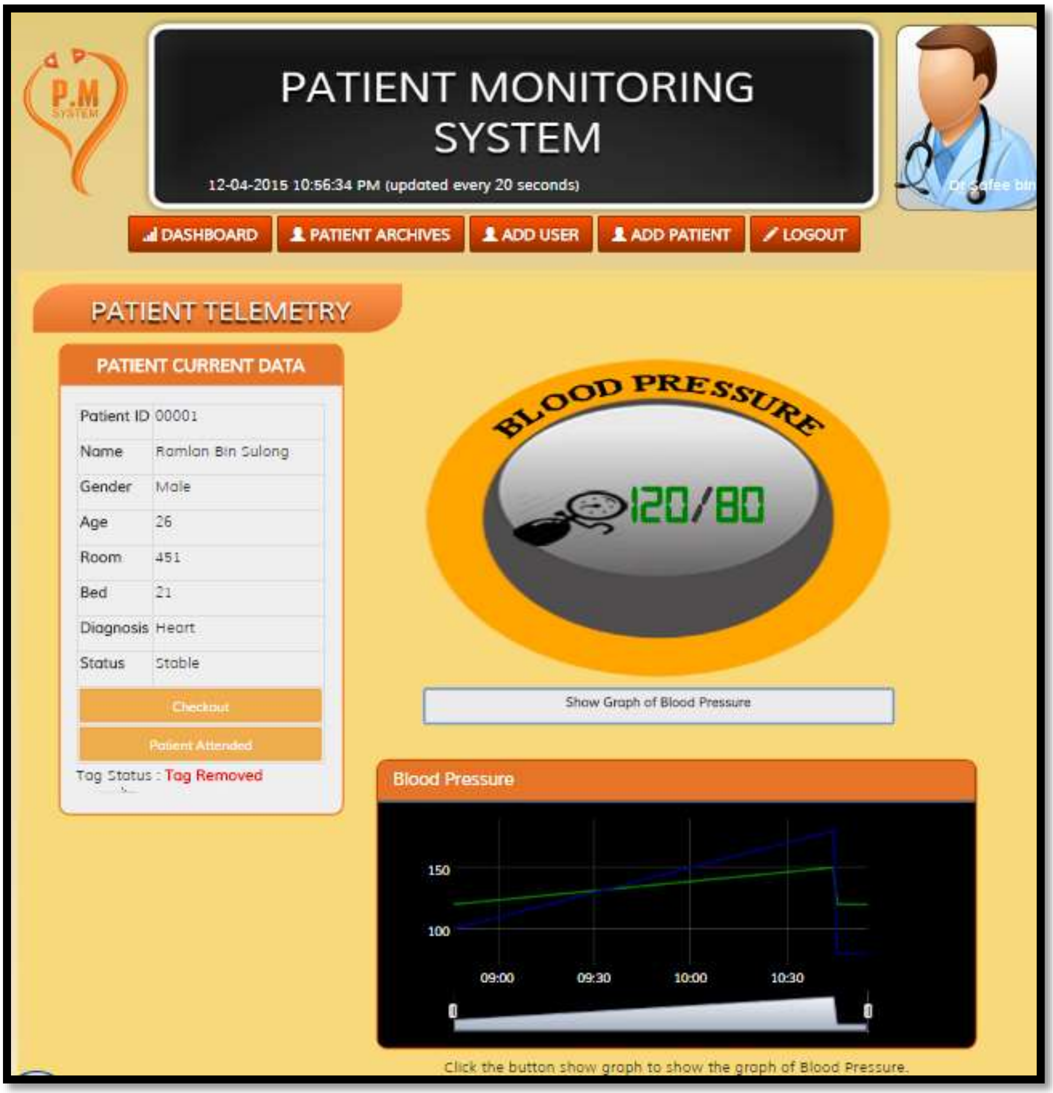


FIGURE 19. Latest systolic and diastolic values

CHAPTER 4
RESULTS AND DISCUSSION

In this chapter, author had discussed on low-pass filter design, calibration and results validation of the measuring device.

4.1 Low-Pass Filter Design

At the first stage of receiving the pressure sensor, author had performed testing and experimentation on the analogue output of the pressure sensor. The purpose of this experimentation is to examine the behaviour of the signal during the compression and after the compression of the arm cuff. From the observation, at 20Hz sampling frequency, it shows that the analogue output from the pressure sensor is fluctuated very high as follows FIGURE 20. When the output is observed at 10Hz sampling frequency, it shows that the fluctuated is eliminated, FIGURE 21. Thus, author had come with the conclusion to employ the low-pass filter that provides 10Hz sampling frequency. This experimentation is using simple Arduino coding and Serial Print to retrieve all the readings. Following are the result of experimentation. By having a low-pass filter circuit at 10Hz sampling frequency, the readings from sensor are smooth and meeting the expectation, FIGURE 22.

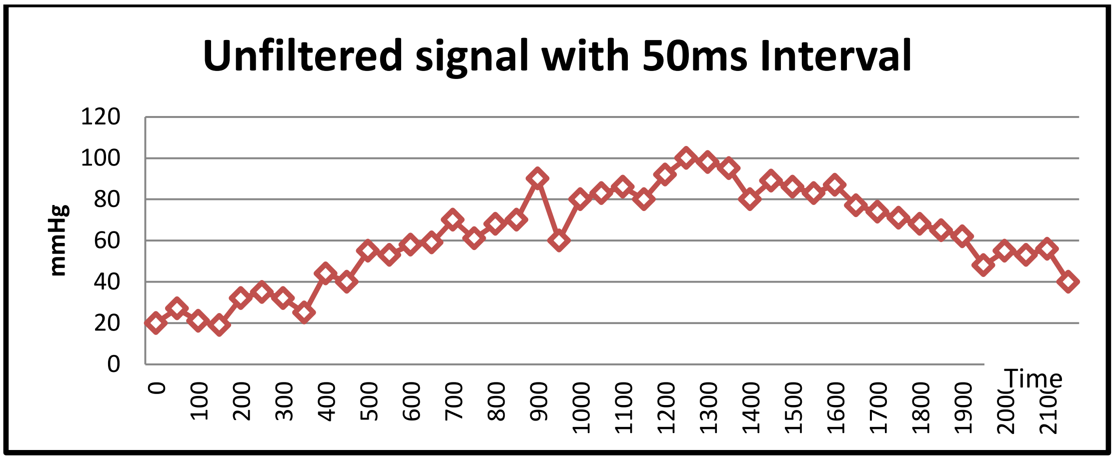


FIGURE 20. Unfiltered signal with 50ms Interval

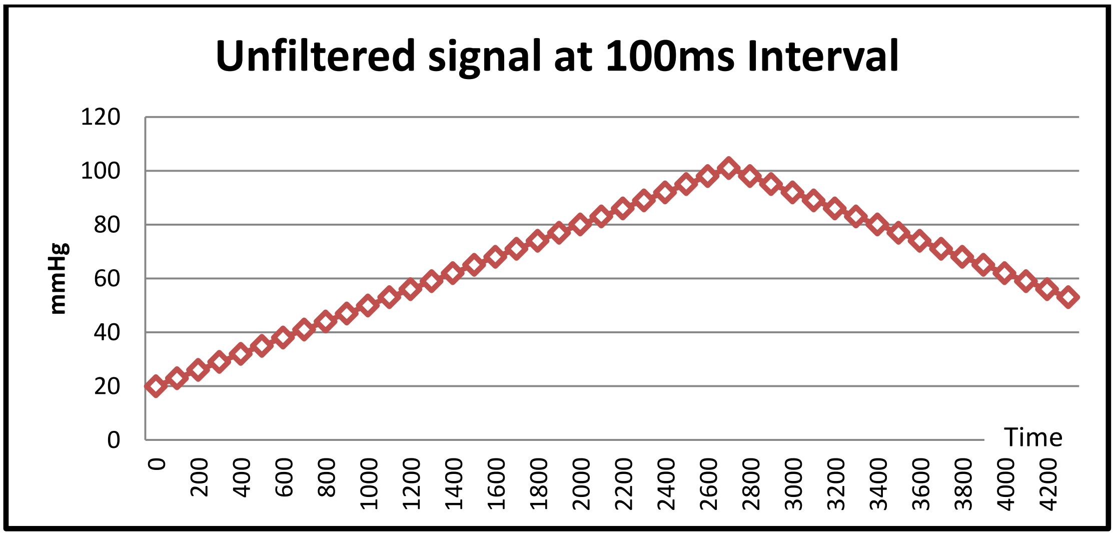


FIGURE 21. Unfiltered signal at 100ms Interval

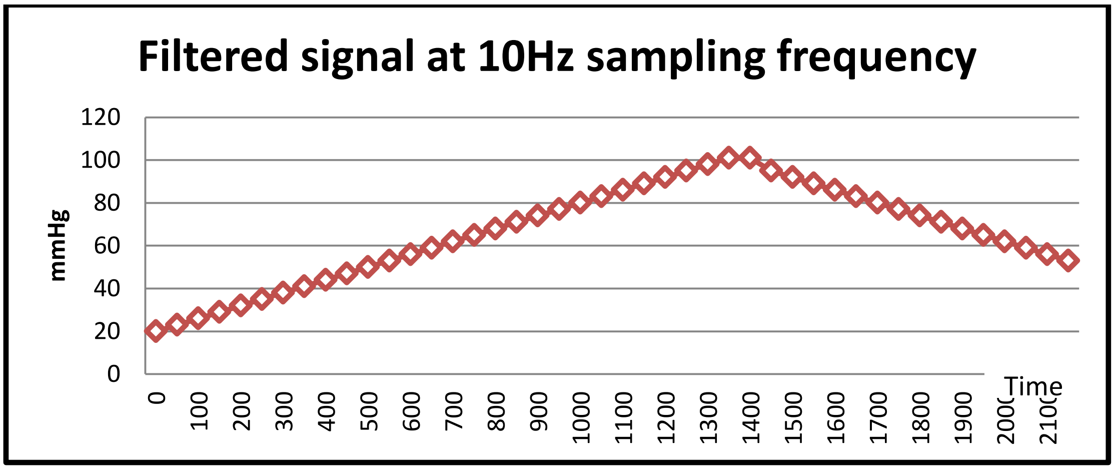


FIGURE 22. Filtered signal at 10Hz sampling frequency

4.2 Calibration

Once the filtering circuit is done, author had performed another experimentation to obtain a coefficient for the pressure value conversion. The purpose of constructing this experiment is to determine the coefficient that should be used in the coding. Because, the range values that used by the controller is differ from the range that provided from the pressure sensor. Below is the conversion that involved:

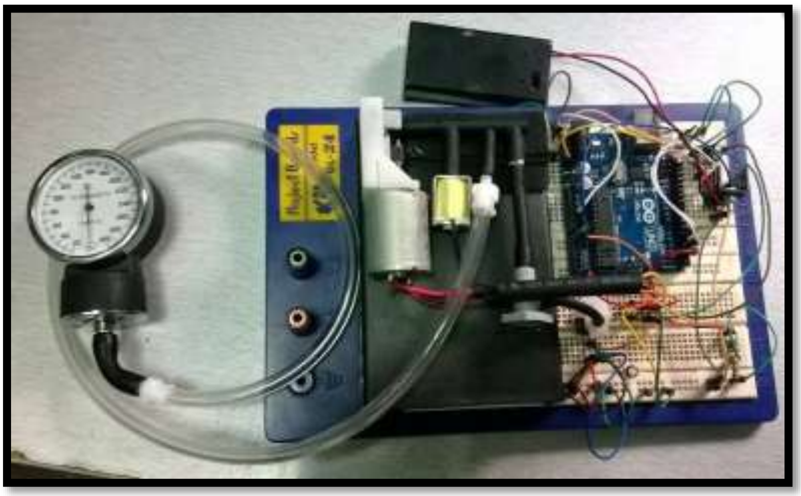


FIGURE 23. Device connected to sphygmomanometer

TABLE 5. Theoretical Values

Components	**Range**
Arduino	0-1023 (0-5V)
Pressure Sensor	0-260mmHg (0-5psi)

Even though the scales are linear to each other, however author's thought it is better to have the coefficient from the practical value rather than theoretical value. From the theoretical value, the coefficient is:

= 260mmHg/1023

= 0.254

However, it found that the obtained values from the experimentation there are differ from the theoretical value as follow TABLE 6:

TABLE 6. Practical Values

Experiment Result	
Gauge at 120mmHg	Arduino value = 407
Gauge at 160mmHg	Arduino value = 540
Gauge at 180mmHg	Arduino value = 605
Gauge at 200mmHg	Arduino value = 680

- 120/407 = 0.295
- 160/540 = 0.296
- 180/605 = 0.298
- 200/680 = 0.295

From the obtained samples, author had decided to use **0.295** as coefficient value since it is the mean value from all the obtained samples.

4.3 Result validation

After the measuring device is successfully implemented, author had tabulated a comparison data with the data that measured by the existing BP Measuring device which manufactured by Omron. In order to ensure the validation of the results is acceptable and reliable, author had tested the measuring device on different persons with different ages which ranged from 21 to 41 years old and mostly of them are born and raised in Asian. There are also from different type of people with different carrier, and life style which consists of students, technicians, security officer and floor manager. From the obtained data, author had decided to tabulate the data into group of ages instead of carrier, genre and lifestyle. This is because; the obtained results show there have significant different if the data is tabulated based on different group of ages. Following are the obtained data for systolic and diastolic values.

TABLE 7. Result Validation

Group of Age(s)	**SYSTOLIC**	BP Sensor (mmHg)	Omron (mmHg)	**Percentage Error (%)**
21-25	Sample A	120.98	122	**0.836**
	Sample B	123.33	120	**2.775**
	Sample C	195.39	196	**0.311**
26-30	Sample D	120.91	123	**1.670**
	Sample E	125.47	121	**3.677**
	Sample F	123.55	120	**2.958**
31-41	Sample G	130.41	134	**2.679**
	Sample H	125.33	127	**1.315**
	Sample I	124.69	129	**3.341**
	Average Error (%)			**2.131**
	DIASTOLIC	BP Sensor (mmHg)	Omron (mmHg)	**Percentage Error (%)**
21-25	Sample A	79.11	83	**4.686**
	Sample B	83.41	79	**5.582**
	Sample C	83.34	81	**2.888**
26-30	Sample D	83.69	85	**1.541**
	Sample E	80.46	82	**1.878**
	Sample F	80.11	84	**4.630**
31-41	Sample G	87.88	90	**2.356**
	Sample H	88.56	86	**2.977**
	Sample I	83.05	85	**2.294**
	Average Error (%)			**3.203**

Based on the obtained results, it shows that the measuring device is giving reliable values as its average error for both diastolic and systolic values are below 5 per cent from the certified electronic BP measurement (Omron).

CHAPTER 5
CONCLUSION AND RECOMMENDATION

As a conclusion, the project is finished between the time frame that given by UTP. This project is utilized very less number of hardware thus will ease to implement hence will give reliable and accurate result.

Author had read through the past project thesis which has the same topic as this project. It found that there are some aspects that have been improved in this project. First of all is about the selection of the pressure sensor. It found that the previous project used pressure sensor which ranged up to 700kPa while it's only required 50kPa of maximum measurement. By using the sensor that has a very huge resolution, it will reduce the accuracy of the results. Secondly, it found that the position of tubing are not fixed thus will introduce disturbance to the results. This is also the possible reason of giving inaccurate result. Lastly, the coding should have a proper algorithm and coefficient that used to convert the kPa or Psi to mmHg unit.

As a recommendation, throughout several literature reviews, author had found that the BP measuring device will provide better result if it is using **Fuzzy Logic algorithm** instead of normal comparison of the pressure values. Now days, Fuzzy Logic is widely used in electronics medical equipment especially in BP measuring device. It will provide better result in term of accuracy and also will provide best estimation. In term of communication, it is recommended to establish a monitoring system that have a **duplicate BP measuring device (multiple)** integrated with wireless medium in the same receiver node. In real application, there is more than one patient that uses the BP measuring device. In addition, the project also can be improved in terms of size. The prototype is possible to be embedded in **smaller size** and proper casing to ensure that it will convince and comfort when it attached to the patient's arm.

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APPENDIXES

1. Coding

```
#include <SoftwareSerial.h>
SoftwareSerial xbee(0,1);
const int buttonPin1 = 2;
const int ledPin1 =  3;
const int ledPin2 =  4;
const int buttonPin2 = 5;
const int buttonPin3 = 6;
const int buttonPin4 = 7;
const int buttonPin5 = 8;

#define sensorValue analogRead(A0)

void setup() {
  pinMode(ledPin1, OUTPUT);
  pinMode(ledPin2, OUTPUT);
  pinMode(buttonPin1, INPUT);
  pinMode(buttonPin2, INPUT);
  pinMode(buttonPin3, INPUT);
  pinMode(buttonPin4, INPUT);
  pinMode(buttonPin5, INPUT);
  Serial.begin(9600);
  xbee.begin(9600);
}
int
try1=0,delay_interval=0,count=0,x1=0,x2=0,sen=0,der1=0,dia=0,sys=0,dia_p=-
1,sys_p=-1;
float dia_value=0.0,sys_value=0.0;
void loop()
{
 try1=0;count=0;x1=0;x2=0;sen=0;der1=0;dia=0;sys=0;dia_p=-1;sys_p=-1;
 dia_value=0.0;sys_value=0.0;
 if ((delay_interval==0) || (delay_interval==1))
while(!digitalRead(buttonPin1));
 digitalWrite(ledPin1, HIGH);
 digitalWrite(ledPin2, HIGH);
 while(sen <= 550)
 {
   sen=sensorValue;
 }
 digitalWrite(ledPin1, LOW);
 count=0;
 dia=0;
 sys=10000;
while(sen >= 220)
{
sen=sensorValue;
x2=sen;
der1=(x2-x1);
if(der1>1)
  {
    if(count>200)
    {
  if(sys>count){sys=count;sys_p=sen;}
  if(dia<count){dia=count;dia_p=sen;}
    }
  }

x1=x2;
count++;
delay(10);
}
```

```
digitalWrite(ledPin2, LOW);
dia_value=dia_p*0.3173;
sys_value=sys_p*0.3163;
Serial.print("0001 ");
Serial.print(dia_value);
Serial.print(" ");
Serial.println(sys_value);

delay_interval=0;
if ((digitalRead(buttonPin2)) && (!digitalRead(buttonPin3)) &&
(!digitalRead(buttonPin4)) && (!digitalRead(buttonPin5)))
delay_interval=2000;
else if ((!digitalRead(buttonPin2)) && (digitalRead(buttonPin3)) &&
(!digitalRead(buttonPin4)) && (!digitalRead(buttonPin5)))
delay_interval=4000;
else if ((!digitalRead(buttonPin2)) && (!digitalRead(buttonPin3)) &&
(digitalRead(buttonPin4)) && (!digitalRead(buttonPin5)))
delay_interval=6000;
else if ((!digitalRead(buttonPin2)) && (!digitalRead(buttonPin3)) &&
(!digitalRead(buttonPin4)) && (digitalRead(buttonPin5)))
delay_interval=8000;
else delay_interval=1;
delay(delay_interval);
}
```

2. Specification of Pressure Sensor

Part #: HSCDRNN400MGAA5

Part Category: Sensors/Transducers
Manufacturer: Honeywell Sensing and Control
Description: ABSOLUTE, PEIZORESISTIVE PRESSURE SENSOR, 0-5.8Psi, 0.25%, RECTANGULAR, THROUGH HOLE MOUNT

See PDF Datasheet

Print
Email
Bookmark

SPECIFICATIONS

Mfr Package Description	ROHS COMPLIANT, CERAMIC, DIP-8
EU RoHS Compliant	Yes
Status	Active
Sensors/Transducers Type	PRESSURE SENSOR,PEIZORESISTIVE
Accuracy-Max (%)	0.25
Body Breadth	9.91 mm
Body Height	5.9 mm
Body Length or Diameter	13.35 mm
Housing	CERAMIC
Mounting Feature	THROUGH HOLE MOUNT
Number of Bits	12
Operating Current-Max	3 mA
Operating Temperature-Min	-20 Cel
Operating Temperature-Max	85 Cel
Output Type	ANALOG VOLTAGE
Package Shape/Style	RECTANGULAR
Port Type	BARBED
Pressure Range-Min	0.0 Psi
Pressure Range-Max	5.8 Psi
Pressure Sensing Mode	ABSOLUTE
Response Time	1000 μs
Supply Voltage-Min	4.75 V
Supply Voltage-Max	5.25 V
Terminal Finish	NOT SPECIFIED
Termination Type	SOLDER
Additional Feature	TEMPERATURE COMPENSATED OVER 0 TO 50 DEG