FINAL YEAR PROJECT 2

DEVELOPMENT OF CONTINUOUS REMOTE BLOOD PRESSURE MONITORING SYSTEM

By

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FINAL REPORT

Submitted to Electrical & Electronics Engineering Department

in partial fulfilment of the requirements for the

Bachelor of Engineering (Hons)

(Electrical & Electronic Engineering)

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CERTIFICATION

CERTIFICATION OF APPROVAL

Development of Continuous Remote Blood Pressure Monitoring System

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A project dissertation submitted to the

Electrical and Electronics Engineering Programme

Universiti Teknologi PETRONAS

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Approved:

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UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

Sept 2013

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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ABDILLAH BIN NASIB

ABSTRACT

The conventional method to measure blood pressure of human is either by using a manual measurement by qualified personal (doctors or nurses) using *sphygmomanometers* or an automatic measurement completed via blood pressure devices. Both of these methods however have a drawback that may lead to misidentification or fatalities. For manual measurement; there are many parameters that may lead to misreading patient's blood pressure such as the level of patient's nerve due to the environmental factor (doctors office), while the automated measurement that widely used in hospital has to be monitored manually at certain time intervals by a nurses.

If patients experience a high or low blood pressure in this time interval, the nurses will not know until the next measurement is to be taken. This situation may cause a serious injury to the patients, or even worse a fatality or permanents damaged such as stroke. Hence, the main objective of this project is to develop a continuous blood pressure monitoring system for a patient with the usage of *Wireless System* module.

The system used for measurement of blood pressure are design based on the Oscillometric Blood Pressure devices, where the readings of systolic, diastolic and mean artery pressure obtained by pumping controlled air pressure to the wrist cuff. The readings of blood pressure obtained will be transmitted with wireless transmitter, to the designated wireless readers (tags) where it will displayed on the monitor at nurses stations. Through this system, patient's blood pressure is able to be monitored continuously and they may be stored for future references. The essential part of this system is to automatically generate an alarm to alert the nurse station when patients' blood pressure exceed or fall below the predefined limits on systolic and diastolic level respectively.

ACKNOWLEDGEMENTS

Alhamdulillah, with the will and the permission from Allah SWT, I successfully completed this Final Year Project. Although, the objectives of this project are completely achieved, there are some minor defects in term of output readings accuracy. From this project, not only the knowledge that I gain but through this project I also gain the experience to become more responsible and appreciate on people contribution for me on this project.

Therefore, my highest appreciation I give to my supervisor and co-supervisor Final Year Project, Dr. Hanita Binti Daud and Ir. Dr. Nursyarizal Bin Mohd Nor for their support, ideas and guidance towards the completion of this project. Their guidance helps me to makes continuous progress in every week throughout the completion of this project.

I would also like give appreciation to all my colleagues for their support and ideas throughout the period, specifically to Nurul Fauzana Binti Imran Gulcharan and Muhammad Afham Bin Mohd Azhar. Other than that, I also like to thank all laboratory technologists specifically to Mr Azhar Bin Zainal Abidin and Mr Mohamad Yasin Bin Baharudin for their cooperation given and also the guidance for me throughout the project completion.

Last but not least, many thanks to my colleagues and family members who have supported me throughout the project completion. Thank you for your continuous support and cooperation in giving and sharing some ideas for this project.

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INTRODUCTION

1.1. OVERVIEW OF PROJECT

This project is conducted in order to develop an automatic device and system that can measure blood pressure of any patients continuously and generates alert if blood pressure readings are exceed or fall below predefined limits. The necessity of this project is highly demand nowadays, where it may improve the existing system in medical and health application.

The improvements to the existing system are concerned to reduce the human error due to misidentification, while the other factor is to minimizing the risk of fatalities from misreading between time intervals (hospital routine) with a system that are able to continuously monitored the patients, and even able to alerting the responsible personal in the time of emergency.

In this paper, there are two major parts that will be discuss comprehensively, the first parts is the efficiency and reliability of the measurement device and the second part is the integration of measurement device with the wireless system. Further discussion on the next section will be on the background study, problem statement, objective and scope of study, literature review and the last part is methodology.

1.2. BACKGROUND STUDY

At present, the technology used for the measurement of blood pressure are done automatically with the electronic version of Oscillometric blood pressure device, where is more accurate compared to the earlier version such sphygmomanometers and the Korotkoff methods. However, both of these methods required a manual observation by a certain personal such a doctor or nurses. In a case where patients admitted into the hospital's ward, nurses will only come at certain time intervals to monitor the patient's condition, including patient's blood pressure. If, by some misfortune the patient experienced an attack of high blood pressure between this time intervals, there is nothing could be alerted to the nurses and may lead to serious injury or even fatalities.

The purpose of this project develop is to improvise the existing technology used in current practice, which means the author proposed to develop a system that are able to monitored patience blood pressure from computer at remote workstation. The general idea of this project is computer will received patience blood pressure readings (data) from a sensor equip at patience side. From the data appeared on computer, many workforces (e.g. nurse and doctor) able to access and monitored it without required them to present at patience side. Further improvement which proposed to be implement on this project is his system also able to trigger alarm (alerting that some patient need attention) and keep patients record (the medical parameters).

1.3. PROBLEM STATEMENTS

As have been discussed on the previous section, the author has identify a several problem with the existing technology and system applied in medical and health care which is;

a) The risk of patient being not treated due to misreading between times visiting (hospitals' routine).
b) The existing technology and system is work semi-automatic, which required nurses are present at the patient side to manually record the blood pressure readings.

Hence, in order to overcome this problem, where patients' blood pressure readings undetected between visiting interval, the author are proposing this project, where the outcome from it will be a device which shall monitor patients' blood pressure readings automatically and generate an alerts to nurses work station or computer if the readings exceed or fall below the predefined limits of systolic and diastolic levels respectively.

1.4. OBJECTIVES & SCOPE OF STUDY

On this proposed project, the author strongly strives to overcome the problem that has been discussed in the previous section. As been clarified earlier, there are two main objective of this project which is:

a) To develop devices which shall detect patients' systolic and diastolic levels automatically at predetermine time interval and displaying the readings on the screen attached.

b) To integrate Wireless System to those device which shall transmit the reading to the designated reader allocated at nurse work station and able to generate an alert if the readings exceed predefined limits on the system.

CHAPTER 2

LITERATURE REVIEW

2.1. INTRODUCTION

This section, the author discussed on literature review and only focusing on the blood pressure and the risk of high blood pressure, especially to determine the systolic and diastolic pressure, an existing device on the market to measured blood pressure, oscillometric methods, calibration of measurement device for better accuracy, and the wireless system, precisely ZigBee wireless technology.

2.2. WHAT IS BLOOD PRESSURE?

Blood pressure is defined as a strength that is required for the heart to pump the blood through a blood vessel known as arteries all the way through the entire blood circulation system. As a living organism, human's heart are beating normally around 60 to 100 beats per minutes, from this heart beats blood are pumped thru the arteries in order to supply the energy and oxygen required by the body[1].

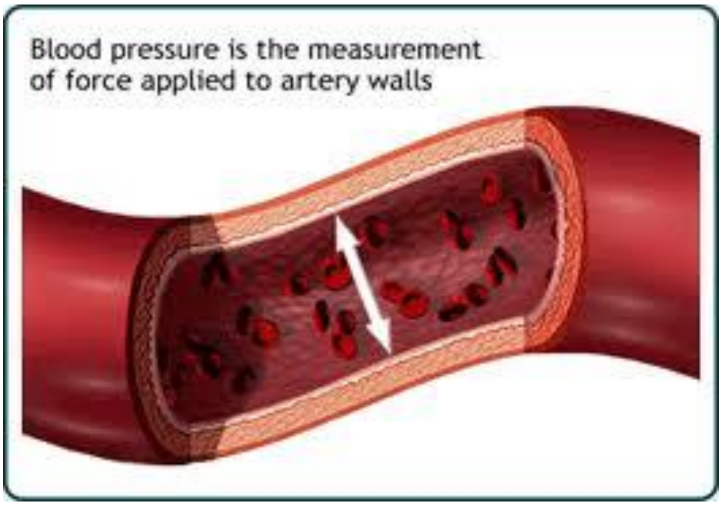

Figure 1: Human Artery [1]

The unit for blood pressure measurement is on millimetre of mercury, and there are 3 main parts that are stressed on the blood pressure measurement, which is systolic pressure, diastolic pressure and mean artery pressure. Normal readings for healthy individual are ≤120mmHg for systolic pressure, ≤ 80mmHg for diastolic pressure and the mean artery pressure is around 90mmHg. Blood pressure is well known as one of parameters to determine the health level of individual person.

From the predefined limit stated above, if systolic pressure exceed the limit of 120mmHg while diastolic pressure fall below 50mmHg ,it may lead to the symptom of pre-hypertension and without a proper concern, it may leads to hypertension cases which could cause a major permanents damage to the body such as stroke.[1]

There are so many method of blood pressure measurements recorded in human history, but the *Oscillometric* methods appear as the most commonly applied and used in the medical and health care discipline. Through this methods, a controlled air pressure are pumped thru the cuff that been wrapped around the patients wrist until the blood circulation stop. Then, the controlled air pressure are slowly being released while the electronics components will measured electronically, during the inflation and deflation process and used to determine the systolic, diastolic and mean artery pressure by means proprietary algorithm.[2]

2.3. BLOOD PRESSURE MEASUREMENT DEVICE

Rapuno, E.B.a.S (2010) discussed on the Oscillometric methods, specifically on comparison of this method to the conventional method of blood pressure measurement i.e. Korotkoff methods. As a clarification of the Oscillometric measurement method, a controlled air pressure will be pump through the cuff wrist of the patient until it stopped the blood circulation. After that, the pressure will deflated slowly while the device reads the blood pressure electronically during the inflation or deflation phase, and used to estimate the systolic and diastolic by means property of algorithm.

Even though Oscillometric methods are widely used in real world application, this methods still has a minor drawback from internal and external factors. For internal factors, this methods somehow a affected by uncertainty components due to the lacking of calibration on the air pressure sensing system and from the systolic and diastolic pressure estimation algorithm[2].

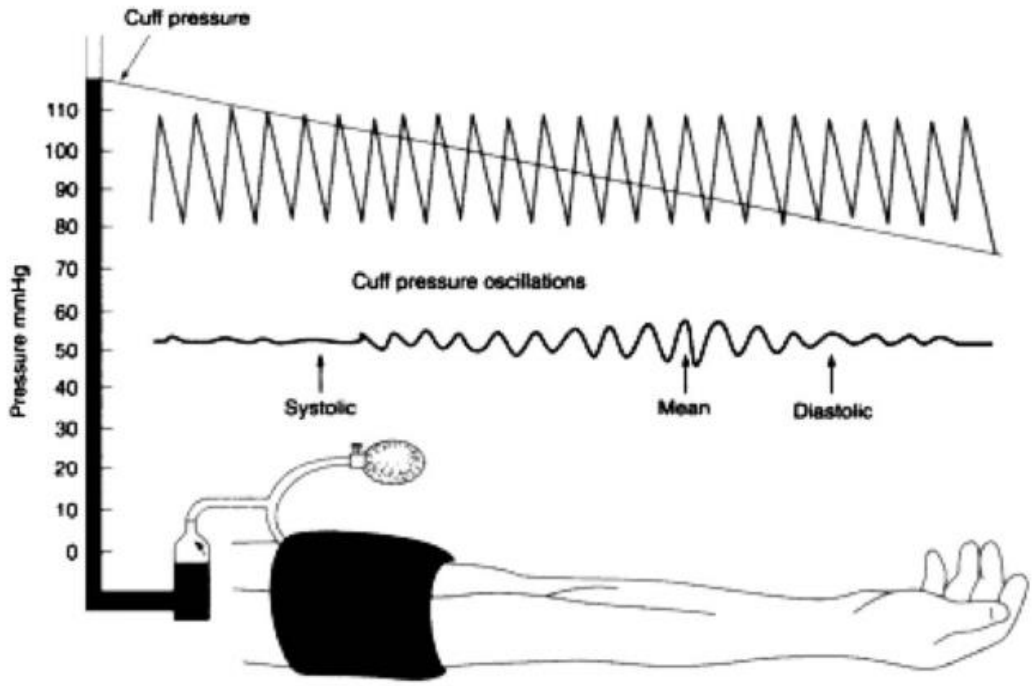

Figure 2: BP determination according to oscillometric method [2]

While for an external factor, uncertainty could be related due to measurement conditions, position of patients' arm during the test and the physical condition of patients itself. The author stressed that each of the blood pressure measurements device has to be calibrate frequently in order to ensure the accuracy of reading a patients' blood pressure.

Pickering, T.G. et al. (2005) investigates medical approach to preventing, detection, evaluation and treatments for problem of high blood pressure. The data from this research paper is very useful for the implementation of the author project because it give a clear distinction of human blood pressure. The data clarifies the limitation of systolic and diastolic pressure that will be implemented on this project. It also discusses the external factor that may contribute an inaccuracy to blood pressure readings such as the location of measurements, validation of device and preparation of the subjects. The most preferred location of measurements are around the wrist and it is positioned at the same level of the heart , when patients are on relax sitting position, leg uncrossed and not under any medication or drugs effect.

The last parts is on the validation of the device where it strongly recommended to passes a set of calibration process especially on the accuracy of pressure registrar on algorithm system. Through validation process, it prepared guide line and future reference of the devices' accuracy and will be improved the reliability of device itself. The accuracy of readings holds the highest priority on each measurement device, because it may lead to a bigger problem such as mistreatment or misidentification of patients' condition.[1]

Since the oscillometric methods used a mathematical algorithm in blood pressure measurements, all the data of blood pressure reading are on the form of digitized value represented on graphical waveform. On the oscillometric waveform, usually it distinguish two distinct peak, where first peak representing systolic peak pressure occurred on inflation phase while second peak representing diastolic peak pressure on deflation phases.

Another version blood pressure measurement based on the oscillometric method called as oscillometric morphology method. Systolic (SBP) and diastolic pressure (DBP) are estimated via signal-based approached and it utilized to derive a methodology in order to estimate the mean arterial pressure (MAP). It clarified the derivation of Mean Arterial Pressure from systolic and diastolic peak pressure on the oscillometric waveforms, (MAP = DBP + 1/3 (SBP - DBP)).

This article has proved that the feasibility of the Oscillometric Pulse morphology in blood pressure from non-invasive oscillometric measurements. The result from this research paper will softening the data analysis process later on particularly on this project.[3] The other method based on oscillometric method called as via controlled linear deflation method that been discussed on the Development of a New Oscillometric Blood Pressure Measurement system. The advantage of this method compared to the other was it granted a faster and most important part which is precision of the readings.

The improvement was made on the cuff deflating process and the creation of new algorithm. From this research paper, it provided with the most appropriate method determining the systolic and diastolic pressure which is: 1) Fixed Percentile Rule (also known as Fixed Ratio). This rule implements a fixed value of systolic and diastolic ratio and the mean value of characteristic ratios determined in the data based study. It stated that the systolic mean ratio = 0.5573, while for diastolic mean ratio = 0.7608. 2) Characteristic ration in relation to pressure rule. This rule applied on each oscillometric pulse based on determination of characteristic ratio for each pressure level.

The result of this research paper was clarified through an evaluation of the new system design and comparative testing using simulator. It showed a significant increment in difference on the observed reading and the calculated reading via the new system with the implementation of fixed percentile algorithm. As been required from Associations for Advancement of Medical Instrumentation - AMMI recommended limits; the result also proved the mean difference and standard deviation for systolic and diastolic pressure were ± 5mmHg and ± 8mmHg respectively.[4]

2.4 WIRELESS SYSTEM (ZigBee Wireless System)

Originally, in order to make this project working automatically, the first idea was to integrate the blood pressure measurement devices with Active RFID communicator. But, after reviewing the previous project done by Mr Izzuddin Mohd Sani, the author decide to used wireless system due to better performance of transmitting and receiving the data. Hence for the second technology which will be reviewed here is wireless system specifically for blood pressure monitoring application.

The article specified the type of wireless device which called as ZigBee wireless transmission due to convenient of low power consumption for communication process. The system architecture comprises with analogue circuit, arm-based platform, ZigBee wireless modules and lastly the management unit. It give a comparison on the manual blood pressure measurement test where it required user to recoding the data manually, while with the integration with wireless communicator will overcome the necessity of manual data recordings.

The article stress on the integration process between the measurement device with the ZigBee wireless module. The challenge also lies on the process on getting the most accurate readings. The resulting data then compared with CuffLink Blood pressure simulator because it can simulate from the normal blood pressure readings, hypertensive and hypotensive dynamic waveform. The integration with ZigBee wireless modules able to provide a continuous monitoring towards the patient, thru this integration, a user-friendly system could be provided.[5]

There is one major problem that happens frequently on the wireless system called as *Gaussian Noise.* As been experienced in many electronic circuits especially on biomedical application, the interference between the wireless modules are commonly comes from power line frequency used and it components. i.e. 50Hertz. The interference may affected system reliability and accuracy, hence on this article it provides a precise protocol for wireless embedded system called as *ZigBee 802.15.04 Protocol*.

The justification of the chosen protocol were; 1) Due to the big capacity of the ZigBee network, it provided an ad-hoc function for adding more embedded systems-pad, allowing more flexibility in network topology. 2) Range cover above 100 meters, due to lower power consumption. 3) ZigBee use high frequency ranged 2-4 GHz; hence it will not affect by the electromagnetic field and increased the system reliability. 4) Extra power source are did not required due to low power consumption. 5) Equip with security tool box including access control list, data freshener timer and 128-bit encryptions. The implementation of this protocol resulting a system that more accurate, reliable and low power consumption. These advantages point will truly useful during the construction of this project.[6]

As been discussed by Clark and Park (2006), there is an important reason to having a reliable and accurate wireless system specifically on the clinical application. The burst on electronic technology industries has been increased number of products on the market that been integrate with wireless system as an improvement to the existing technology. This however increasing the risk of having inaccurate or unreliable of wireless system due to competition between manufacturer. On this article, author specifically identified and assesses the risk from wireless system implemented on the clinical application i.e. level or zone identification.

The implications from having poor-performance of wireless system may lead to various bad effects such wrong level in order to attempting help the patient and worst case scenario could cause the system undelivered an important readings of the patients at specified time. The outcome of this article clearly stressed that by having a wireless system is not good enough, but it has to be reliable and accurate at the same time. As for this proposed project, where the application is for blood pressure measurement, it is very crucial for the system for having a higher percentage of reliability and accuracy [7].

CHAPTER 3

METHODOLOGY AND PROJECT'S WORK

3.1. INTRODUCTION

The methodology part showing process and project flows thru flow chart and Gantt Chart and project's work progress explaining on the current progress of the project; simulation on the software and selection of hardware used for this project.

3.2 METHODOLOGY

Methodology is used as a guideline of the project systematically. The following flow chart is showing methodology part of this project and the Gantt chart used as works guideline through these eight months.

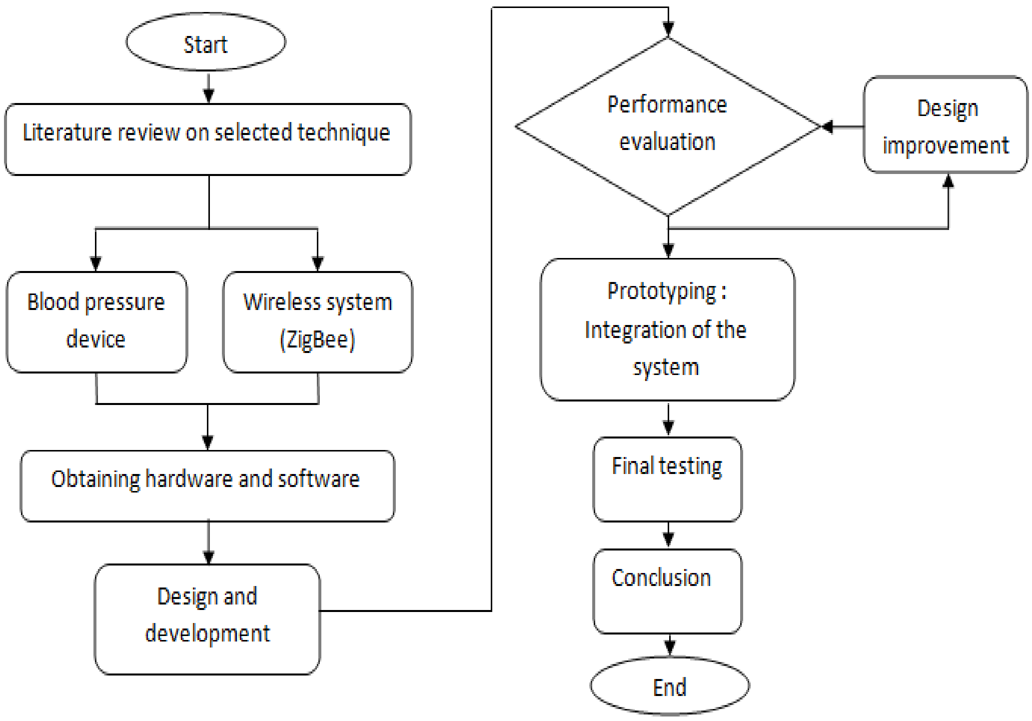

Figure 3: Methodology Flow Chart.

Table 1 Gant Chart

Details/Month	May	June	July	August	September	October	November	December
Selection of project title	■							
Research (Literature Riview)	■	■	■					
Simulation (Design Modeling)	■	■	■	■	■			
Submission of Extended Report		■						
Proposal Defense			■					
Testing and Analysis			■	■	■	■	■	
Submission of Interim Report				■				
Prototyping and Fabricating					■	■	■	
Submission of Progress Report							■	
Pre-SEDEX							■	
Submission of Dissertation (Soft Bound)								■
Submission of Technical Report								■
Final Viva								■
Submission of Dissertation (HardBound)								■

3.3 PROJECT WORK

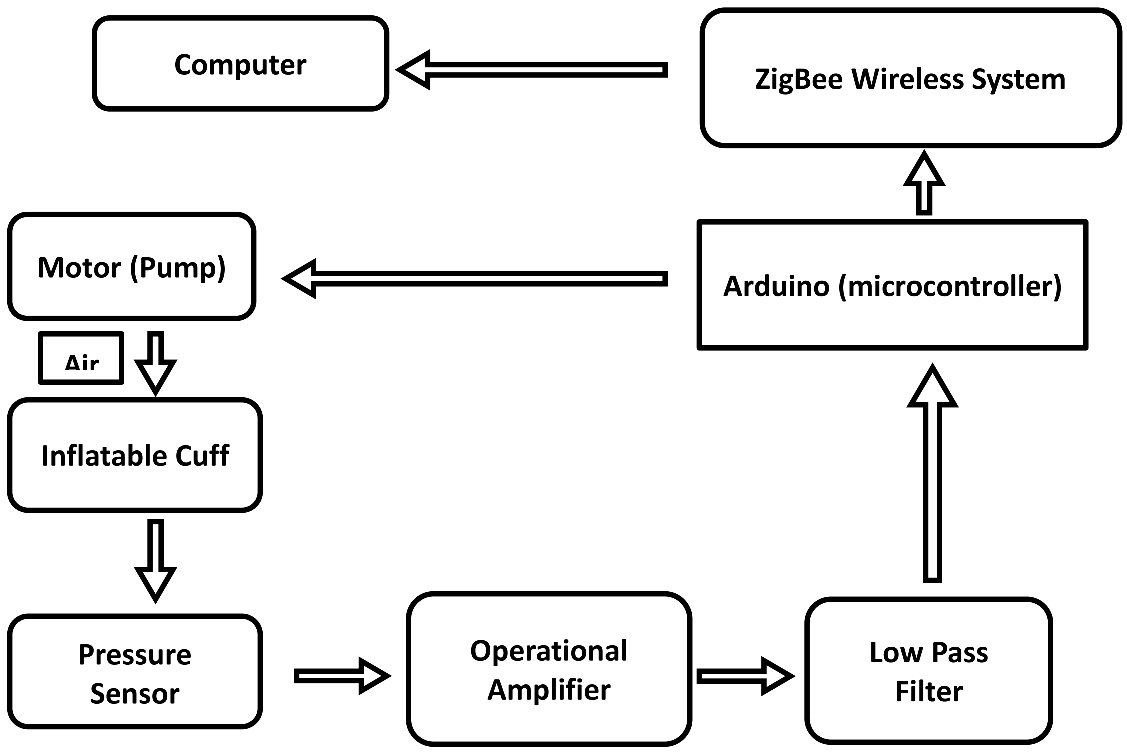

Figure 4: System Architecture

From Figure 4 above, the process started with pumping a pressurized air from the motor to inflatable cuff. The air pressure is set and controlled from the programming on microcontroller (Arduino). During this inflation process, pressure sensor will measure the pressure inside the cuff and generating output to DC component.

This output then amplified by certain type of amplifier specifically high precision op-amp, low noise and quiescent current in order to minimizing the noise. After air pressure reach it maximum pressure (as been set on programming), motor will stop pumping the air, and those pressurized air will be released slowly from the cuff. This process called deflates process, where at this process microcontroller will analyse the output to determine systolic and diastolic pressure separately. Finally, the readings will be transmitted thru ZigBee wireless tag to computer or others display unit.

3.4 TOOLS USED

In this section, the core hardware components of this project will be briefed. There are 4 major components that are very important and will determine the successful rate of this project. The following subsection will explained these components and justification of choosing it.

3.4.1 PRESSURE SENSOR

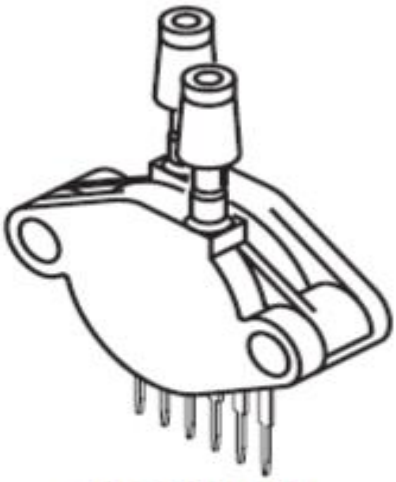

Figure 5: Pressure Sensor (Freescale Semiconductor)

Pressure Sensor in this project used as a component that will detect air pressure passing thru it. As been explained before, a pressurized air pumped from the motor to inflatable cuff and it passing thru this component. Originally, this component will generate two type of output which is DC signal and AC signal, but only DC output will be used and measured since this project only has DC source to power-up. The output will be amplified with operational amplifier, which be explained on next subsection. The reason to amplified the output signal because it is too small, making it hard to be detected and measured by microcontroller [8]

3.4.2 OPERATIONAL AMPLIFIER

Operational amplifier are a type of differential amplifier, where the output potential typically multiplied by certain value so it will larger then input potential and called as gain. On this project, the requirement for op-amp is low power, high precision and low output noise. This because, as others measurement device, this project has to have high accuracy in order to maintain the stability and reliability.

Figure 6: OPA2314-EP

3.4.3 MICROCONTROLLER (ARDUINO)

In this project, microcontroller used known as Arduino .The hardware consists of a simple hardware board designed based on Atmega-328 microcontroller, consist 14 pins for input or output, 16MHz built-in crystal oscillator, a USB connection, a power jack and a reset button. The software consists of a standard programming language compiler and a boot loader that executes on the microcontroller, a power jack, an ICSP header, and a reset button. Notes that out of 14 digital input/outputs pins, there are 6 of them can be used as PWM outputs. The analogue inputs are connected with built-in ADC where capable to convert or quantize 0 V to5 V analogue inputs into 1024 level digital input (0 to 1023, 9 bits) [9].

Figure 7: Arduino Microcontroller

3.4.4 ZIGBEE WIRELESS SYSTEM

ZigBee Wireless System was used in this project because of certain functions it can provide which met the requirements of the whole system. The very important function of this system were the frequency cover-up ranged above 100 meters without required an extra power source due to lower power consumption. The others function which really useful for this project were it provide an ad-hoc function for additional embedded system-pad, allowing more flexibility to network topology.

Last but not least, ZigBee use a high frequency for it wireless communication, where it range between two to four giga hertz (2-4 GHz), hence it frequency will not be affected by electromagnetic field and it will increase the system reliability. ZigBee Wireless System comprises 2 main components, which is transmitter part and receiver part. Generally, transmitter part will collect the data (output readings) from the blood pressure circuit and transmit it to designated receiver [10].

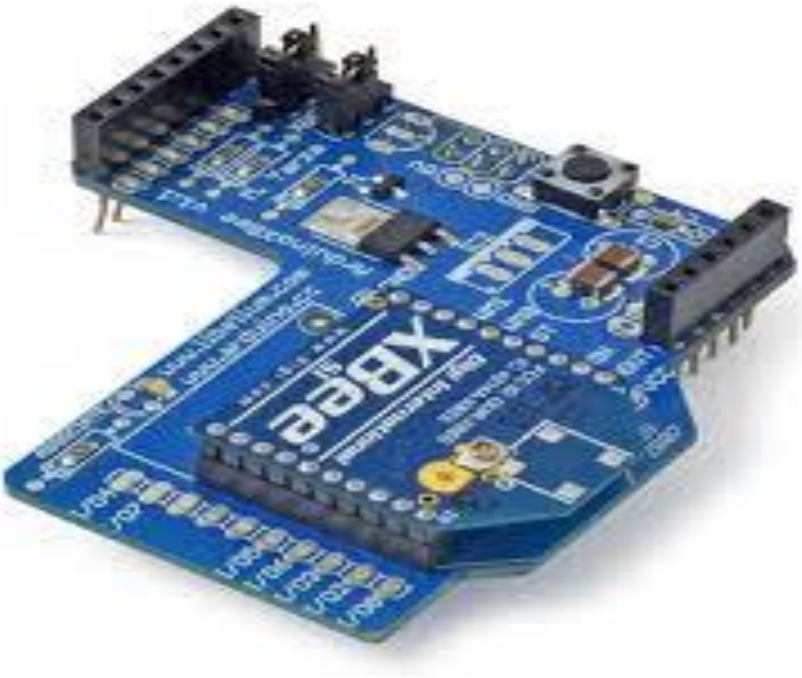

Figure 8: ZigBee Transmitter Part

Figure 9: ZigBee Receiver Part

3.4.5 MOTOR PUMP AND AIR VALVE

An Oscillometric method comprises inflation and deflation process which required separate pump and air valve working together. During inflation cycle, motor will pump an air into arm cuff and solenoid air valve will hold the air in order to create a pressure inside the arm cuff.

After air pressure reach pre-determined level, motor will stop from pumping the air into arm cuff, while solenoid air valve start to release the pressure slowly; known as deflation cycle.

Both of the motor and air valve used in this project supplied with 6VDC, even though there are planning to change these part with smaller one, which only consume 3VDC, but the 6VDC motor and air valve was used till this project completed due to output reading problem which required more attention (trouble-shooting and calibration).

Figure 10: Motor Pump & Air Valve

3.4.5 SUPPORT TOOLS

Throughout the process of developing this project, there are several tools used frequently. These tools can be dividing to hardware and software tools. Below is the list of support tools used in their category;

Table 2 : Support Tools (Hardware)

No	Tools	Description
1	DC Power Supply	Used to provided DC voltage, usually used during calibration process in Lab.
2	Digital Multimeter	Used to check voltage and current on the circuitry, sometimes used to check connectivity of electrical components on this project.
3	Soldering Kit	Used to solder all components on PCB board.

Table 3 : Support Tools (Software)

No	Tools	Description
1	Open source Arduino Development software	Used to writing compiling the programming codes and uploading the programming codes into Arduino board.
2	Microsoft Excel	Used to analysing the BP data and collecting the data during calibration process before the programming codes is written on Arduino software.
3	Spice Simulation	Used to running the simulation for LP Filter.
4	X-CTU Software	Interface software for ZigBee wireless system. This software used to display readings data after transmission process.

CHAPTER 4

RESULT AND DISCUSSION

4.1 OVERVIEW

In this chapter, the matters about the technical information of the project and the results will be discussed.

4.2 FINAL RESULT

Throughout the time frame given for this project, the project is completed as proposed design concept. However, the blood pressure measurement device was built with some minor defect of reading accuracy problems. The integration of blood pressure measurement device with ZigBee wireless system has given an outstanding performance, where the overall readings accuracy defect was not rising after the integration process.

4.3 OVERALL CIRCUIT

The overall circuit of this project comprises three major components, each of them hold a significant role to the entire circuitry performance. The first component is electrical parts, which comprises of 6Volts DC motor, 6Volts solenoid air valve and two set of DPDT relay. While the second component is analogue parts, which comprises of pressure sensor (Freescale-MPX 5700), operational amplifier and single low pass filter. The third component is digital parts, which comprises of microcontroller (Arduino) and ZigBee wireless transducer.

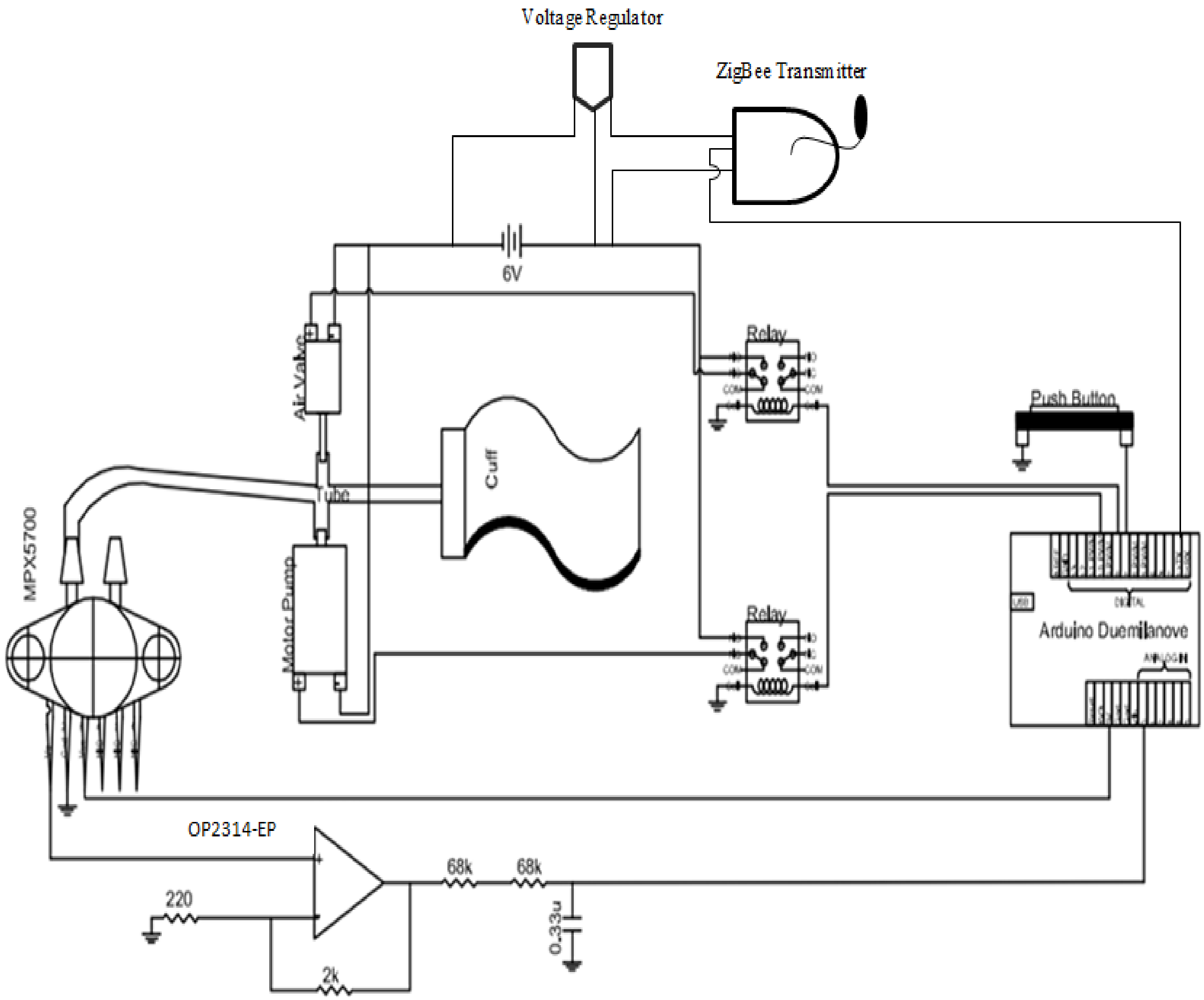

Figure 11: Overall Circuit Diagram

As been shown in Figure 11 above, the overall circuit designed to operate using separated 6 V power supply because the solenoid air valve and motor pump required supply of 6 VDC. Therefore, the 6 V power supply is required as an external power supply since the Arduino board only capable to supply 3.3 V and 5 V. The OP2314-EP op-amp uses two power supplies which are 5 V (positive terminal) from the Arduino board and 6 V (negative terminal) form 6 V power supplies [9].

Generally, the pressure sensor will produce an output signal reflecting the pressure inside the arm cuff. Then, the signal will amplify and filter before send to microcontroller. Microcontroller then will determine the systolic and diastolic pressure based on the program codes written on it. The result from these codes will be send to ZigBee tag (transmitter) through digital I/O pins, specifically thru pin no 1, which allocated for transmission purposes. The transmitted data then will be received by ZigBee receiver and those data will be display at work station (computer) with the help of X-CTU interface software [10].

Based on previous studies, there is one modification made in order to minimize the readings accuracy defects faced of this project. That component is operational amplifier, were in the previous design it used operational amplifier LM741. The ability of this op-amp could amplify output voltage up to 4.18 Volts, but is not sufficient for this circuit, based on the previous readings data acquired. Therefore, a new op-amp was searched and studied in order to reduce the readings accuracy defects and finally op-amp from Texas Instrument OP2314-EP was chosen to be implementing in this circuit [11].

4.3.1 OPERATIONAL AMPLIFIER (OP2314-EP)

As been discussed from previous report (Interim Report), the operational amplifier holds significant roles in determination on accuracy of the system. As an improvement for this circuit, OP2314-EP operational amplifier is used for this project, where it can amplify the output signal up-to 5.5 Volts. The reason of using this op-amp because the output from the pressure sensor ranged around 0 - 0.5Volts (maximum BP estimated around 350mmHg or 50KPa). Hence, the output signal has to amplified with a gain, K = 9.091. Therefore, in order to achieve that gain, the resistors value selected from 220Ω and 2KΩ. From simulation result (Figure 13), this op-amp should be able to amplify the output signal from pressure sensor up-to 270mmHg, twice larger than extreme human blood pressure [12].

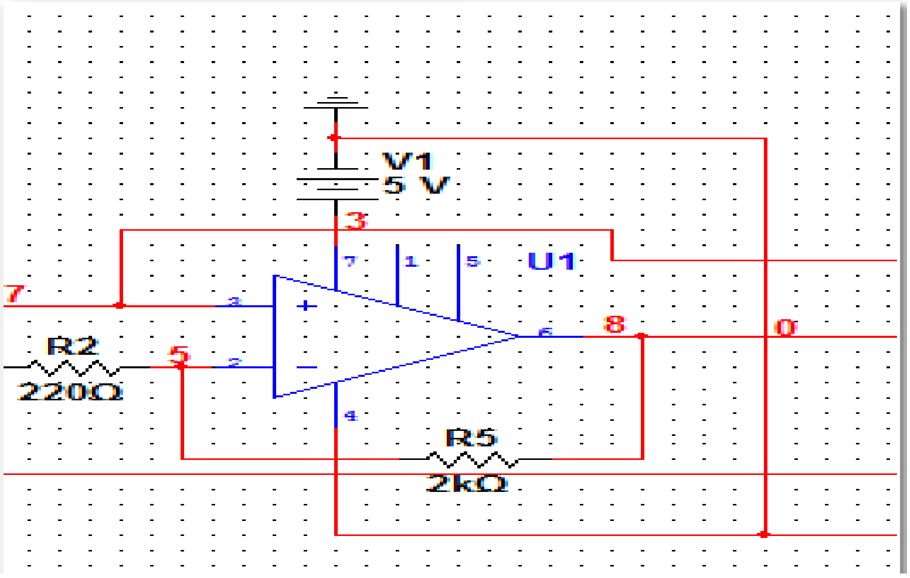

Figure 12: Schematic Diagram of OPA2314-EP

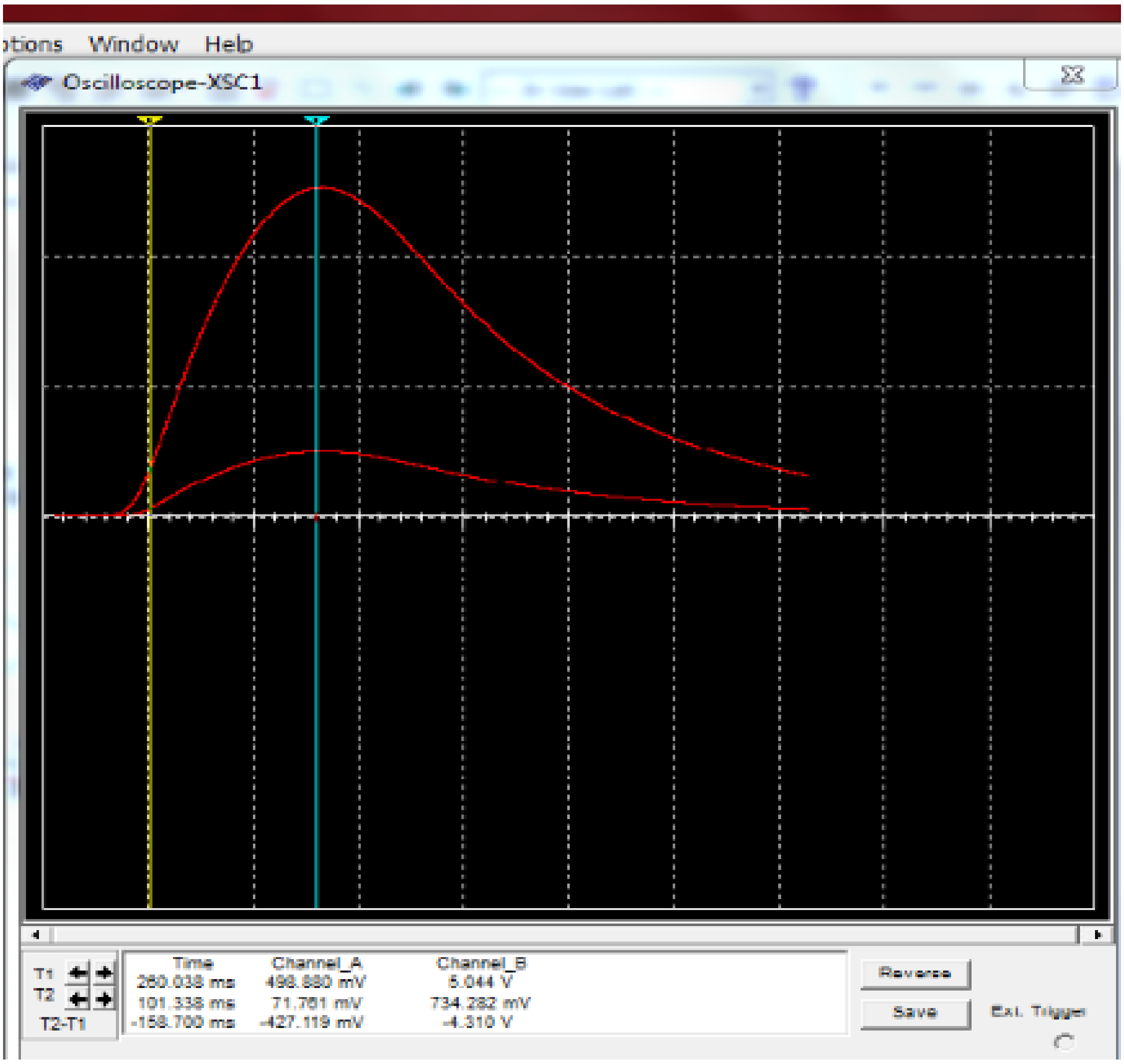

Figure 13: Simulation Result of OPA2314-EP Op-Amp

4.3.2 MICROCONTROLLER (ARDUINO)

As been discussed on literature review, this project used Oscillometric measurement methods in order to determine human blood pressure. In this method, inflation and deflation process of arm cuff will be used to determine the systolic and diastolic pressure respectively. In order to do so, the very first step was calibration of pressure sensor with electronic pressure gauge. Calibration process was done by comparing the digital output from microcontroller with electronics pressure gauge which been attached into a solid material such as water bottle to represent human arm.

This calibration process is done in order to remove atmospheric pressure from being added into the system during the data changing from analogue to digitalized value. This digitalized value is crucial to be precise because it could jeopardize system stability if the value were not accurate. From here, a simple coding was constructed to check the highest possible peak of human blood pressure. The data acquired then tabulated into graphical form were it compared to the estimated graph from oscillometric method.

From these tabulated data, a series of code are written on Arduino microcontroller using Open Source Development Software, interface software to Arduino microcontroller board. These codes are written on C language, and it basically develops on mathematical operation determined by the data acquired from tabulated data on graphical form. Below are samples of tabulated data on graphical form used;-

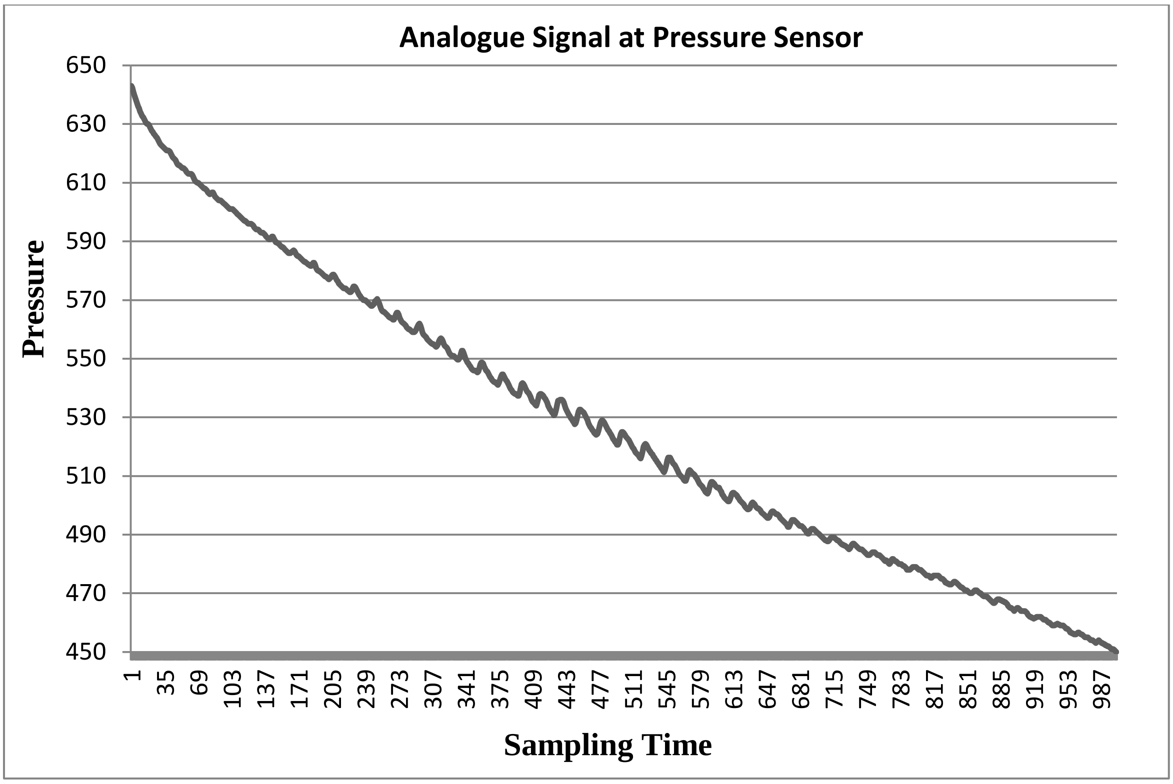

Figure 14: Tabulated Signal data from Pressure Sensor

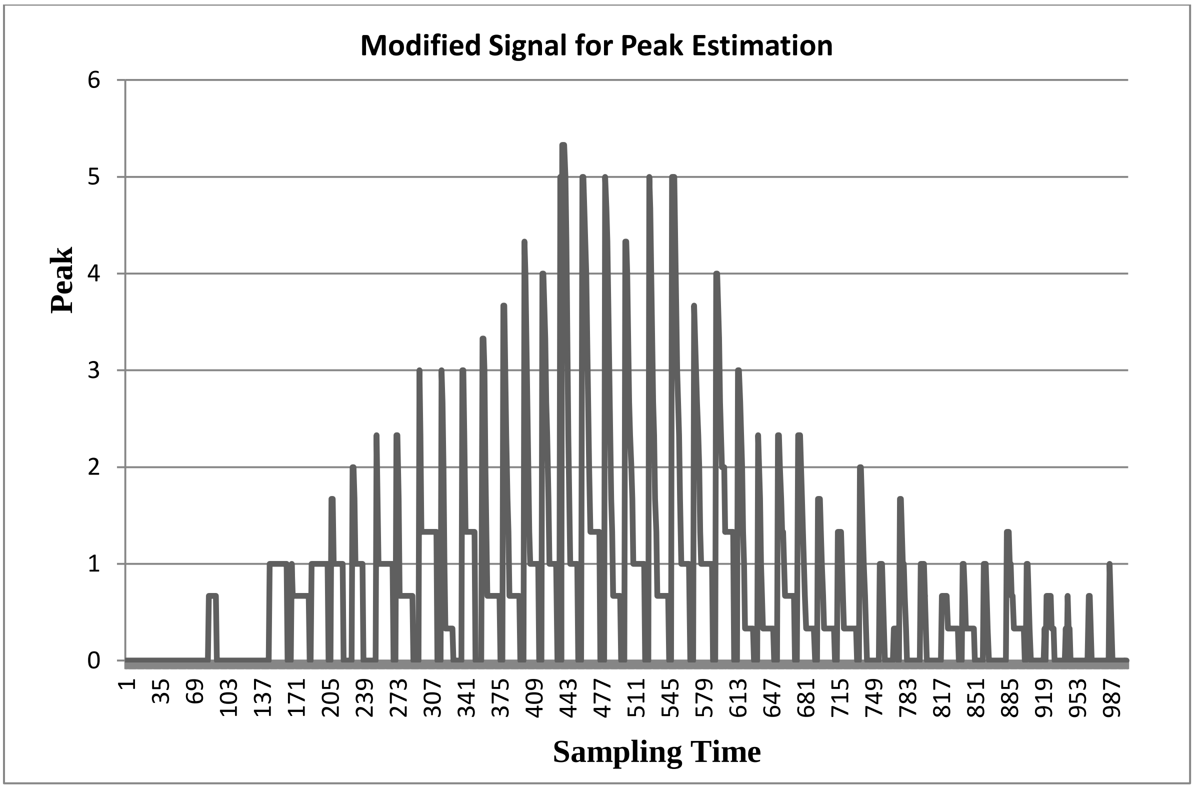

Figure 15: Tabulated Signal data in Peak Estimation

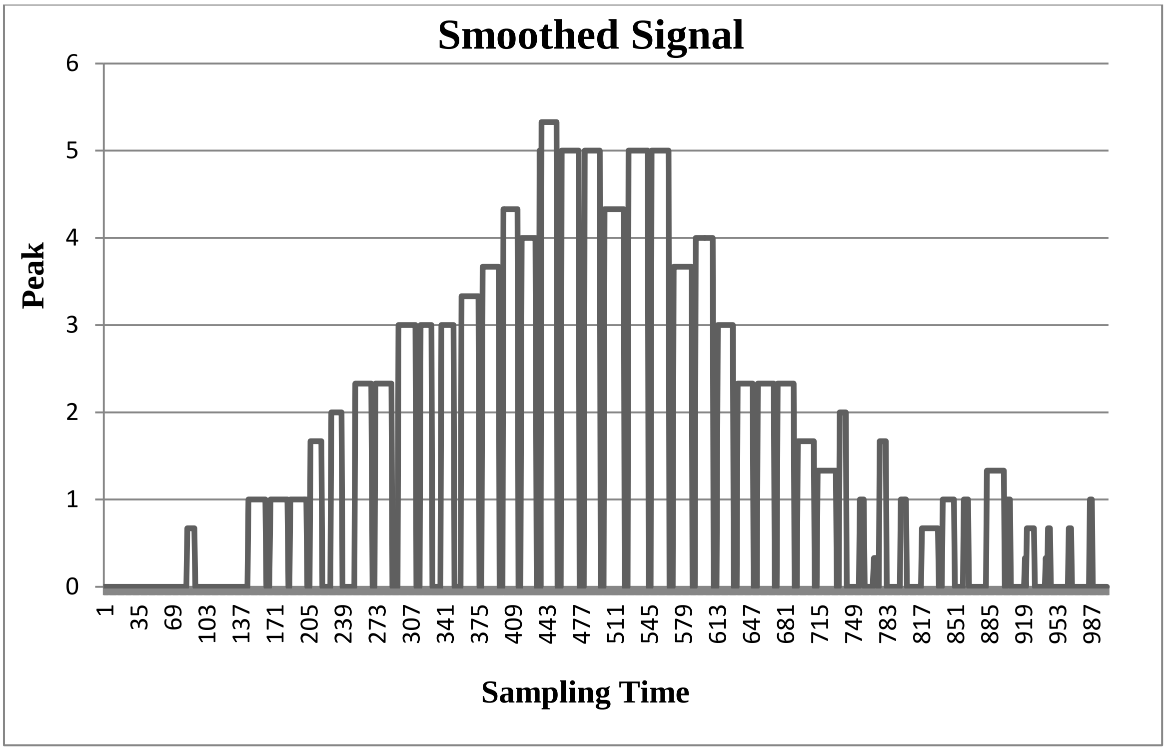

Figure 16: Tabulated Signal data in Real Peak.

From Figure 14 above, acquired data from test of highest possible peaks were turn into graphical form in order to make it easier to be observed and analysed. Observed that the signal readings were start at highest peaks, which means the signal from pressure sensor are being read by microcontroller after the inflation cycle completed. After that, signal readings are slowly decreased and at this stage signal data from pressure sensor were measured by microcontroller.

From graph on Figure 15, the time differences between each possible peak were manipulated by differentiating the current data with previous data that being sampled. As been shown on Figure 16 above, from the initial till final measurement, the difference between each data becomes higher at the centre of measurements process. This situation are concretely suggest that at this stage, blood pressure are being read by pressure sensor since the pressurized air inside arm cuff are slowly released from air valve. Observed that some of the differentiated signals are too low and some of it is too high.

Therefore, the differentiated signal on Figure 15 has to be smoothed by removing the lower and highest data. This process actually used after observing the graph on Figure 15. By simply neglected the lower and highest data from current mathematical operation, the graph on Figure 16 acquired.

On this graph, the estimated peaks become more clear and easy to be observed, hence the real peaks of the signal become more appeared and the digitalized value behind it can be easily traced. Finally, by referring to the digitalized value acquired from signal of real peaks, a final mathematical operation could be written on microcontroller interface software.

Even though the final coding constructed successfully, the actual readings are hardly to be accurate, hence a rigorous calibration process has been done to ensure the accuracy of actual readings could be similar to the reference reading done by existing blood pressure device. In order to checked whether the coding written could bring an accurate reading, a set of measurements process has been taken to volunteer student. The data from measurements process are shown below;-

Table 4 : Readings Comparison between BP Circuitry and OMRON BP Device (using LM741 op-amp)

OMRON BP Device			**BP Circuitry**		
Student	**Systolic**	**Diastolic**	**Student**	**Systolic**	**Diastolic**
1st	115	75	1st	126	68
2nd	117	76	2nd	104	55
3rd	111	72	3rd	125	41
4th	124	81	4th	125	48
5th	112	73	5th	109	56

Table 5 : Analysis of Systolic Pressure from Data on Table 4

	OMRON BP Device	**BP Circuitry**	**|%|**
Student	**Systolic**	**Systolic**	**Percentage Error**
1st	115	126	9.6
2nd	117	104	11.1
3rd	111	125	12.6
4th	124	125	0.81
5th	112	109	2.68

Table 6 : Analysis of Diastolic Pressure from Data on Table 4

	OMRON BP Device	**BP Circuitry**	**|%|**
Student	**Diastolic**	**Diastolic**	**Percentage Error**
1st	75	68	9.3
2nd	76	55	27.6
3rd	72	41	43
4th	81	48	40.7
5th	73	56	23.3

The output readings (data) shown on Table 4 was taken during the early stage of this project constructed. At that stage, the LM741 are used as the op-amp to amplify the signal from pressure sensor. Observed that on Table 5 and 6, the analysis was done separately between systolic and diastolic pressure. Both of the acquired data revealed that the error on the output readings are high and fluctuate between each of the reading. Thus, an improvement was done on the circuit thru exchanging the op-amp used.

Table 7 : Readings Comparison between BP Circuitry and OMRON BP Device (using OP2314-EP op-amp)

OMRON BP Device			**BP Circuitry**		
Student	**Systolic**	**Diastolic**	**Student**	**Systolic**	**Diastolic**
1st	117	68	1st	114.3	61.15
2nd	114	66	2nd	113.56	56.46
3rd	108	50	3rd	109	62
4th	111	65	4th	112.34	52
5th	113	59	5th	111.78	48.65
6th	115	67	6th	109	67.8
7th	111	61	7th	112.34	58.03
8th	101	51	8th	111.78	59
9th	112	65	9th	111.51	60.04
10th	110	63	10th	108.92	58.79

The output readings (data) shown on Table 7 above was taken after changing the operational amplifier used from LM741 to OP2314-EP. Same as previous analysis, the readings comparison of blood pressure measured using this project circuitry with OMRON blood pressure device (reference device for comparison data). The measurement process was done towards ten volunteer students picked randomly without specific parameters such as gender, age, health condition etc. From these data readings, a simple analysis has been performed to check the accuracy of the readings from project circuitry. As well known in engineering society, there is no such a perfect device in real world application, there always a small amount of error especially in measurement device.

Table 8 : Analysis of Systolic Pressure from Data on Table7

	OMRON BP Device	BP Circuitry	|%|
Student	Systolic	Systolic	Percentage Error
1st	117	114.3	2.362
2nd	114	113.56	0.387
3rd	108	109	0.9174
4th	111	112.34	1.1928
5th	113	111.78	1.091
6th	115	109	2.368
7th	111	112.34	0.3322
8th	101	111.78	2.2549
9th	112	111.51	0.439
10th	110	108.92	0.992

Table 9 : Analysis of Diastolic Pressure from Data on Table 7

	OMRON BP Device	BP Circuitry	|%|
Student	Diastolic	Diastolic	Percentage Error
1st	68	61.15	11.202
2nd	66	56.46	16.897
3rd	50	62	19.3548
4th	65	52	25
5th	59	48.65	21.274
6th	67	67.8	1.17994
7th	61	58.03	5.118
8th	51	59	13.5593
9th	65	60.04	8.26
10th	63	58.79	7.16

From Table 7 above, the percentage error of Systolic Pressure acquired from analysis comparison between data measured by using OMRON blood pressure device and data measured by using BP Circuitry are significantly stable with overall percentage error archived to be less than ±3%. However, percentage error for Diastolic Pressure acquired from analysis still higher with stability of the readings fluctuated from one reading to the others.

4.4 DISCUSSION

Due to the problem of diastolic pressure still consists a high value of error, thus a new set of analysis has been done in order to improve the accuracy of the diastolic pressure readings. Therefore, rigorous calibration of mathematical coding has been done with concerning negative peaks on estimation of highest peak process. As mentioned during the progress report of this project, these negative peaks are totally neglected on all previous process, thus by studying and analysing this negative peaks, the diastolic pressure readings could be improvised.

The idea to investigating this negative peaks comes from the understandings on positive peaks which been studied previously based on the Oscillometric methods. Basically systolic pressure captured during the positive cycle which blood being pump from the heart, while diastolic pressure are captured during the negative cycle which blood being pump back into the heart.[2]

As well known, the time difference between these two cycles are extremely close (in millisecond) to each other, thus it hardly to be differentiate. Since the previous calibration and coding analysis was done with neglecting this important parameter, thus the author attempt to improvise the calibration and coding analysis by analysing the systolic and diastolic pressure separately.

For this negative peaks analysis, the method on gathering data from output readings of pressure sensor almost similar to the positive peaks analysis. The main different of these two analysis is the way of the data acquired manipulated. On positive peaks analysis, the data manipulated to by comparing the current data with the previous one to grasp the difference of positive value. Thus, for negative peaks analysis, the same method used but the objective was to grasp the difference of negative value. Below are samples of tabulated data on graphical form used;-

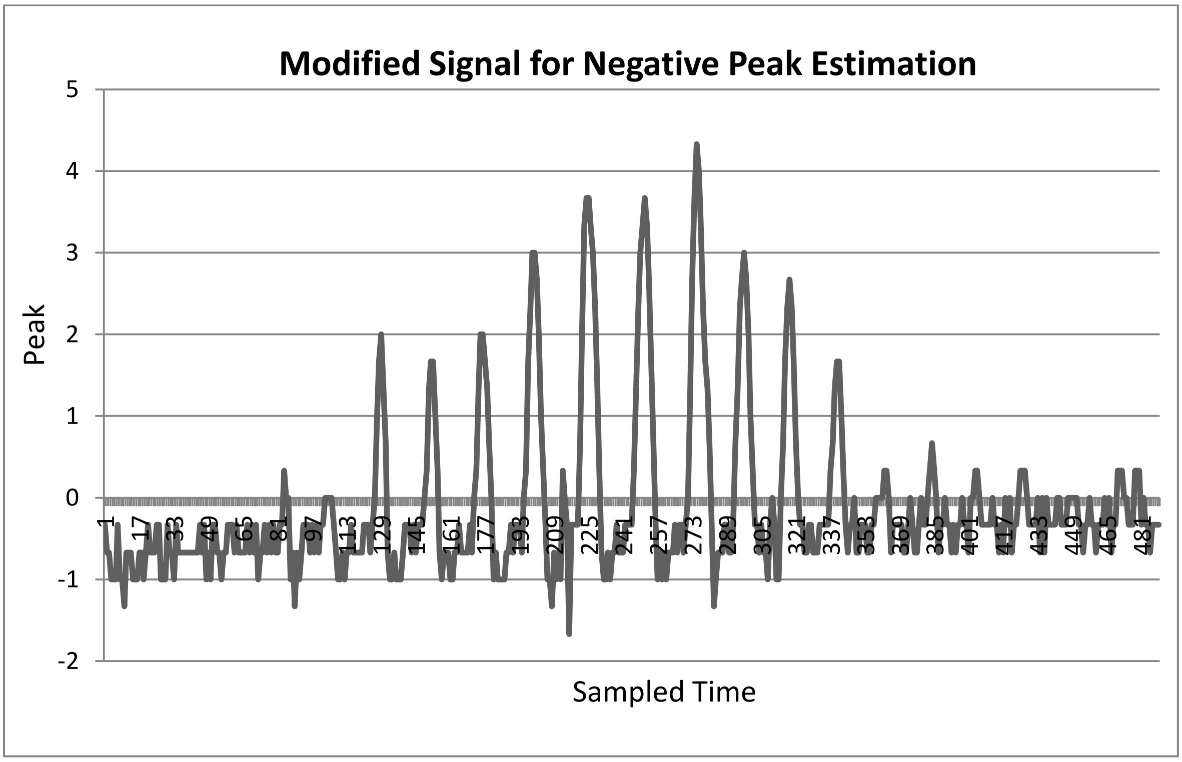

Figure 17 : Tabulated Signal Data for Negative Peaks Estimation

As been shown on figure 17 above, these negative peaks is extremely low, with the average value is one, hence it makes sense when it hard to be captured by the microcontroller during the processing data. Thus, by revising these data, a specific coding was written and inserted to the previous one used on this project. Then a few measurement processes was done by using this new coding, to analyse the output readings error.

Table 10: Readings Comparison between BP Circuitry and OMRON BP Device (after Negative Peaks Improvement)

OMRON BP Device			BP Circuitry		
Student	**Systolic**	**Diastolic**	**Student**	**Systolic**	**Diastolic**
1st	115	66	1st	113.7	62.1
2nd	117	63	2nd	115.76	58.9
3rd	112	69	3rd	111	73.4
4th	111	64	4th	112.34	71
5th	108	60	5th	109.76	56.78
6th	113	65	6th	115	59.73
7th	109	61	7th	111.34	57.28
8th	114	66	8th	112.78	73
9th	112	65	9th	111.51	61.84
10th	110	63	10th	108.92	58.79

Table 11 : Analysis of Systolic Pressure from Data on Table 10

	OMRON BP Device	BP Circuitry	|%|
Student	**Systolic**	**Systolic**	**Percentage Error**
1st	115	113.7	1.13043
2nd	117	115.76	1.05983
3rd	112	111	0.89286
4th	111	112.34	1.20721
5th	108	109.76	1.62963
6th	113	115	1.76991
7th	109	111.34	2.14679
8th	114	112.78	1.07018
9th	112	111.51	0.4375
10th	110	108.92	0.98182

Table 12: Analysis of Diastolic Pressure from Data on Table 10

	OMRON BP Device	**BP Circuitry**	**|%|**
Student	**Diastolic**	**Diastolic**	**Percentage Error**
1st	66	62.1	6.28
2nd	63	58.9	6.96
3rd	69	73.4	5.99
4th	64	71	9.85
5th	60	56.78	5.67
6th	65	59.73	8.82
7th	61	57.28	7.18
8th	66	73	9.58
9th	65	61.84	5.10
10th	63	58.79	7.16

Based on the result analysis on Table 10 till Table 12, even though there is improvement on the diastolic pressure error's percentage, however, the average error percentage still classified as high and above the target value desired. Thus, the overall accuracy of designed BP sensor is still having problem on output readings accuracy defects. Even though a few changes has been done, especially for the op-amp used, coding improvement on negative peaks estimation, the output readings accuracy still comprises a significant value of error that jeopardized the entire circuit stability and reliability.

This accuracy defects suspected comes from the mechanical part (pressure toggle), which held an absolute control to maintain the pressure during the inflation and deflation process. This assumption made after rigorous calibration performed on op-amp circuit, together with program codes improvement. After revising the internal design of actual BP device, this pressure toggle hold a significant role in determines the accuracy of the output readings. Furthermore, this part is highly sensitive where it controlling the releasing air pressure from motor and air valve.

CHAPTER 5

CONCLUSION & RECOMMENDATION

As conclusion, the project is complete as the proposed design with output readings accuracy defects of BP measurement of the BP sensor. The project can be divided into two major parts, which are the BP sensor and network topology for remote monitoring. The output readings transmitted through ZigBee wireless system was not having any defects (error), thus if the reading from the BP sensor can be more accurate, hence this project output will be perfect.

As recommendation for this project, the improvement of the circuit particularly the mechanical part needs to be done. Because, during the entire work process of this project, the electrical parts and program codes was given more priority, till the significant of mechanical part were overlook. The function pressure toggle should be revised properly and the study of flow mechanic should be included for future improvement of this project.

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APPENDICES

APPENDIX A	Fairchild Semiconductor Corporation, Single Operational Amplifier, LM741 Datasheet
APPENDIX B	Freescale Semiconductor MPX5700 Series Pressure Sensor Datasheet
APPENDIX C	Texas Instrument, 3-MHz, Low-Power, Low-Noise, RRIO, 1.8-V CMOS Operational Amplifier, OP2314 Datasheet
APPENDIX D	Blood Pressure Sensor Arduino Code Program (CryNet_Biomed)

APPENDIX A

Fairchild Semiconductor Corporation, Single Operational Amplifier, LM741Datasheet

FAIRCHILD
SEMICONDUCTOR®

www.fairchildsemi.com

LM741

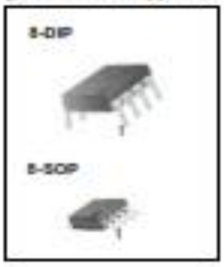
Single Operational Amplifier

Features

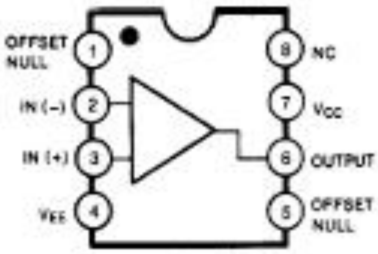
- Short circuit protection
- Excellent temperature stability
- Internal frequency compensation
- High Input voltage range
- Null of offset

Description

The LM741 series are general purpose operational amplifiers. It is intended for a wide range of analog applications. The high gain and wide range of operating voltage provide superior performance in intergrator, summing amplifier, and general feedback applications.



Internal Block Diagram



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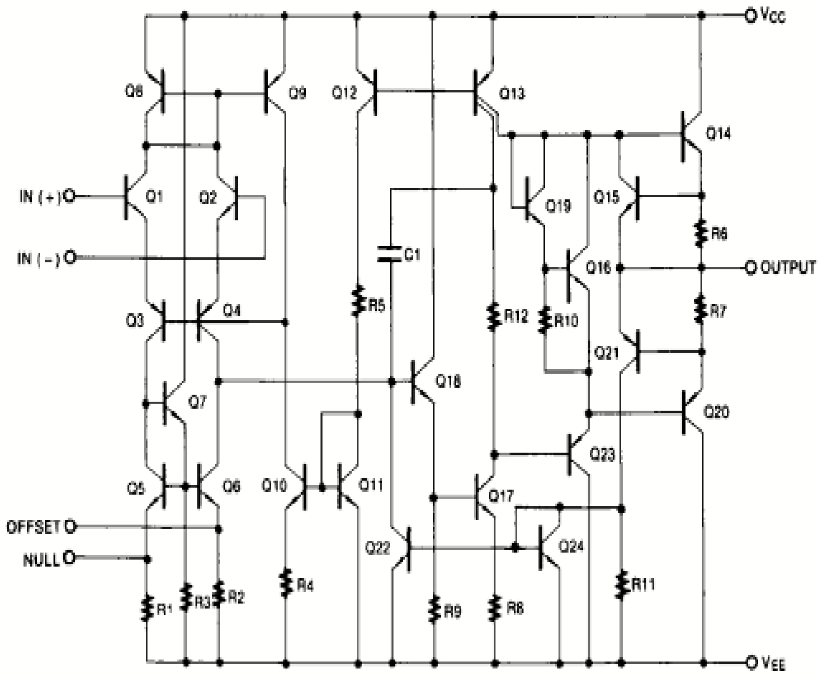
Schematic Diagram



Absolute Maximum Ratings (T_A = 25°C)

Parameter	Symbol	Value	Unit
Supply Voltage	V_{CC}	±18	V
Differential Input Voltage	$V_{I(DIFF)}$	30	V
Input Voltage	V_I	±15	V

Electrical Characteristics

(V_{CC} = 15V, V_{EE} = - 15V. T_A = 25 °C, unless otherwise specified)

Parameter		Symbol	Conditions		LM741C/LM741I			Unit
					Min.	Typ.	Max.	
Input Offset Voltage		V_{IO}	R_S≤10KΩ		-	2.0	6.0	mV
			R_S≤50Ω		-	-	-	
Input Offset Voltage Adjustment Range		$V_{IO(R)}$	V_{CC} = ±20V		-	±15	-	mV
Input Offset Current		I_{IO}	-		-	20	200	nA
Input Bias Current		I_{BIAS}	-		-	80	500	nA
Input Resistance (Note1)		R_I	V_{CC} =±20V		0.3	2.0	-	MΩ
Input Voltage Range		$V_{I(R)}$	-		±12	±13	-	V
Large Signal Voltage Gain		G_V	R_L≥2KΩ	V_{CC} =±20V, $V_{O(P-P)}$ =±15V	-	-	-	V/mV
				V_{CC} =±15V, $V_{O(P-P)}$ =±10V	20	200	-	
Output Short Circuit Current		I_{SC}	-		-	25	-	mA
Output Voltage Swing		$V_{O(P-P)}$	V_{CC} = ±20V	R_L≥10KΩ	-	-	-	V
				R_L≥2KΩ	-	-	-	
			V_{CC} = ±15V	R_L≥10KΩ	± 12	±14	-	
				R_L≥2KΩ	± 10	±13	-	
Common Mode Rejection Ratio		CMRR	R_S≤10KΩ , V_{CM} = ±12V		70	90	-	dB
			R_S≤50Ω , V_{CM} = ±12V		-	-	-	
Power Supply Rejection Ratio		PSRR	V_{CC} = ±15V to V_{CC} = ±15V R_S≤50Ω		-	-	-	dB
			V_{CC} = ±15V to V_{CC} = ±15V R_S≤10KΩ		77	96	-	
Transient Response	Rise Time	TR	Unity Gain		-	0.3	-	μs
	Overshoot	OS			-	10	-	%
Bandwidth		BW	-		-	-	-	MHz
Slew Rate		SR	Unity Gain		-	0.5	-	V/μs
Supply Current		I_{CC}	R_L= ∞		-	1.5	2.8	mA
Power Consumption		P_C	V_{CC} = ±20V		-	-	-	mW
			V_{CC} = ±15V		-	50	85	

APPENDIX B

Semiconductor MPX5700 Series Pressure Sensor Datasheet

Freescale Semiconductor
Technical Data

MPX5700
Rev 8, 01/2007

Integrated Silicon Pressure Sensor On-Chip Signal Conditioned, Temperature Compensated and Calibrated

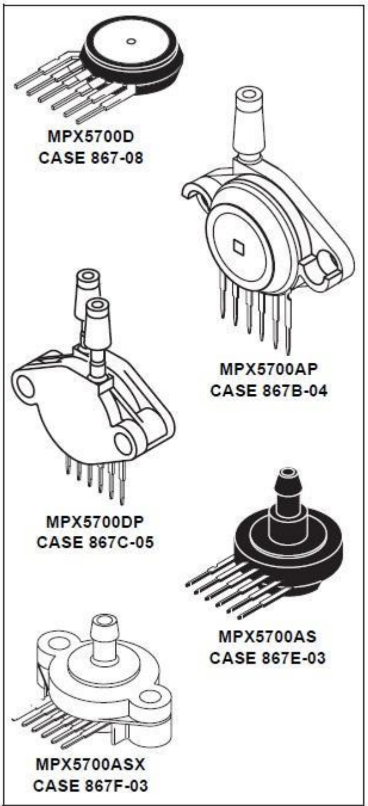
MPX5700 SERIES

INTEGRATED PRESSURE SENSOR
0 to 700 kPa (0 to 101.5 psi)
15 to 700 kPa (2.18 to 101.5 psi)
0.2 to 4.7 V OUTPUT

The MPX5700 series piezoresistive transducer is a state-of-the-art monolithic silicon pressure sensor designed for a wide range of applications, but particularly those employing a microcontroller or microprocessor with A/D inputs. This patented, single element transducer combines advanced micromachining techniques, thin-film metallization, and bipolar processing to provide an accurate, high level analog output signal that is proportional to the applied pressure.

Features

- 2.5% Maximum Error over 0° to 85°C
- Ideally Suited for Microprocessor or Microcontroller-Based Systems
- Available in Absolute, Differential and Gauge Configurations
- Patented Silicon Shear Stress Strain Gauge
- Durable Epoxy Unibody Element



ORDERING INFORMATION

Device Type	Options	Case Type	MPX Series Order Number	MPX Series Device Marking
Basic Element	Differential	867	MPX5700D	MPX5700D
	Absolute	867	MPX5700A	MPX5700A
Ported Elements	Differential Dual Ports	867C	MPX5700DP	MPX5700DP
	Gauge	867B	MPX5700GP	MPX5700GP
	Gauge, Axial	867E	MPX5700GS	MPX5700D
	Absolute	867B	MPX5700AP	MPX5700AP
	Absolute, Axial	867E	MPX5700AS	MPX5700A
	Absolute, Axial PC Mount	867F	MPX5700ASX	MPX5700A

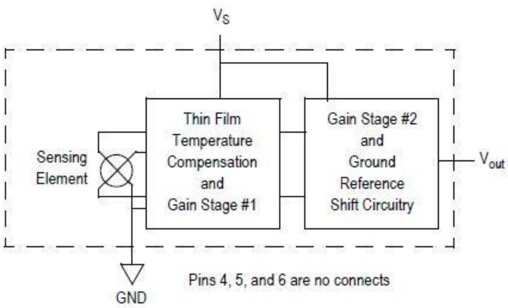


Figure 1. Fully Integrated Pressure Sensor Schematic

PIN NUMBERS

1	V_{out}	4	N/C
2	GND	5	N/C
3	V_S	6	N/C

NOTE: Pins 4, 5, and 6 are internal device connections. Do not connect to external circuitry or ground. Pin 1 is noted by the notch in the lead.

Table 1. Maximum Ratings[1]

Parametrics	Symbol	Value	Unit
Maximum Pressure[2] (P2 ≤ 1 Atmosphere)	$P1_{max}$	2800	kPa
Storage Temperature	T_{stg}	–40 to +125	°C
Operating Temperature	T_A	–40 to +125	°C

1. Maximum Ratings apply to Case 867 only. Extended exposure at the specified limits may cause permanent damage or degradation to the device.
2. This sensor is designed for applications where P1 is always greater than, or equal to P2. P2 maximum is 500 kPa.

Table 2. Operating Characteristics (V_S = 5.0 Vdc, T_A = 25°C unless otherwise noted, P1 > P2. Decoupling circuit shown in Figure 4 required to meet electrical specifications.)

Characteristic		Symbol	Min	Typ	Max	Unit
Pressure Range[1]	Gauge, Differential: MPX5700D Absolute: MPX5700A	P_{OP}	0 15	— —	700 700	kPa
Supply Voltage[2]		V_S	4.75	5.0	5.25	Vdc
Supply Current		I_O	—	7.0	10	mAdc
Zero Pressure Offset[3]	Gauge, Differential (0 to 85°C) Absolute (0 to 85°C)	V_{off}	0.088 0.184	0.2 —	0.313 0.409	Vdc
Full Scale Output[4]	(0 to 85°C)	V_{FSO}	4.587	4.7	4.813	Vdc
Full Scale Span[5]	(0 to 85°C)	V_{FSS}	—	4.5	—	Vdc
Accuracy[6]	(0 to 85°C)	—	—	—	±2.5	$\%V_{FSS}$
Sensitivity		V/P	—	6.4	—	mV/kPa
Response Time[7]		t_R	—	1.0	—	ms
Output Source Current at Full Scale Output		I_{O+}	—	0.1	—	mAdc
Warm-Up Time[8]		—	—	20	—	ms

1. 1.0 kPa (kiloPascal) equals 0.145 psi.
2. Device is ratiometric within this specified excitation range.
3. Offset (V_{off}) is defined as the output voltage at the minimum rated pressure.
4. Full Scale Output (V_{FSO}) is defined as the output voltage at the maximum or full rated pressure.
5. Full Scale Span (V_{FSS}) is defined as the algebraic difference between the output voltage at full rated pressure and the output voltage at the minimum rated pressure.
6. Accuracy (error budget) consists of the following:
   - Linearity: Output deviation from a straight line relationship with pressure over the specified pressure range.
   - Temperature Hysteresis: Output deviation at any temperature within the operating temperature range, after the temperature is cycled to and from the minimum or maximum operating temperature points, with zero differential pressure applied.
   - Pressure Hysteresis: Output deviation at any pressure within the specified range, when this pressure is cycled to and from the minimum or maximum rated pressure, at 25°C.
   - TcSpan: Output deviation over the temperature range of 0° to 85°C, relative to 25°C.
   - TcOffset: Output deviation with minimum rated pressure applied, over the temperature range of 0° to 85°C, relative to 25°C.
   - Variation from Nominal: The variation from nominal values, for Offset or Full Scale Span, as a percent of V_{FSS}, at 25°C.
7. Response Time is defined as the time for the incremental change in the output to go from 10% to 90% of its final value when subjected to a specified step change in pressure.
8. Warm-up Time is defined as the time required for the device to meet the specified output voltage after the pressure has been stabilized.

Table 3. Mechanical Characteristics

Characteristics	Typ	Unit
Weight, Basic Element (Case 867)	4.0	grams

ON-CHIP TEMPERATURE COMPENSATION, CALIBRATION AND SIGNAL CONDITIONING

Figure 3 illustrates both the Differential/Gauge and the Absolute Sensing Chip in the basic chip carrier (Case 867). A fluorosilicone gel isolates the die surface and wire bonds from the environment, while allowing the pressure signal to be transmitted to the sensor diaphragm. (For use of the MPX5700D in a high-pressure cyclic application, consult the factory.)

The MPX5700 series pressure sensor operating characteristics, and internal reliability and qualification tests are based on use of dry air as the pressure media. Media, other than dry air, may have adverse effects on sensor performance and long-term reliability. Contact the factory for information regarding media compatibility in your application.

Figure 2 shows the sensor output signal relative to pressure input. Typical, minimum, and maximum output curves are shown for operation over a temperature range of 0° to 85°C using the decoupling circuit shown in Figure 4. The output will saturate outside of the specified pressure range.

Figure 4 shows the recommended decoupling circuit for interfacing the output of the integrated sensor to the A/D input of a microprocessor or microcontroller. Proper decoupling of the power supply is recommended.

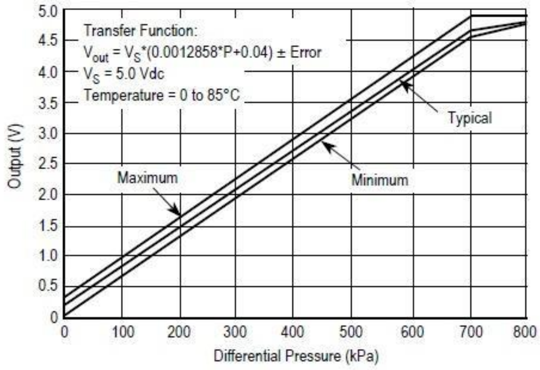


Figure 2. Output versus Pressure Differential

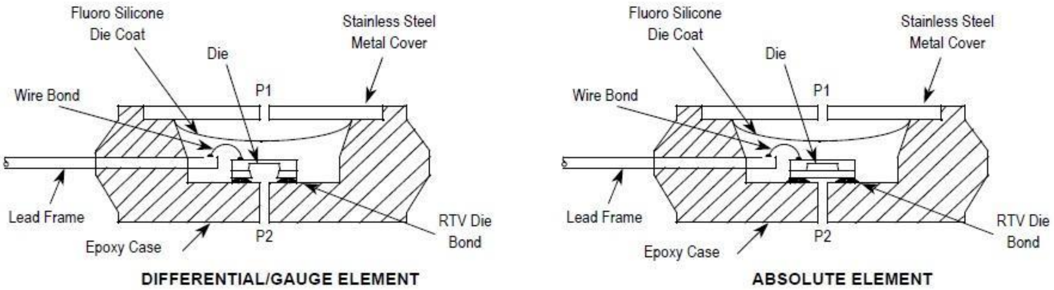


Figure 3. Cross-Sectional Diagrams (not to scale)

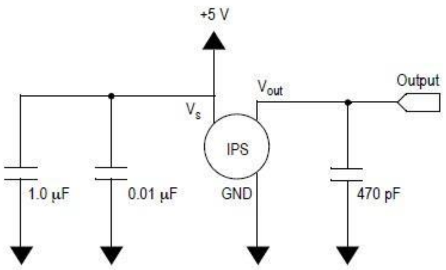


Figure 4. Recommended Power Supply Decoupling and Output Filtering
(For additional output filtering, please refer to Application Note AN1646)

APPENDIX C

Texas Instrument, 3-MHz, Low-Power, Low-Noise, RRIO, 1.8-V CMOS Operational Amplifier, OP2314 Datasheet

TEXAS INSTRUMENTS

OPA314
OPA2314
OPA4314

www.ti.com

SBOS563F – MAY 2011 – REVISED AUGUST 2013

3-MHz, Low-Power, Low-Noise, RRIO, 1.8-V CMOS Operational Amplifier

Check for Samples: OPA314, OPA2314, OPA4314

FEATURES

- **Low I_Q: 150 µA/ch**
- **Wide Supply Range: 1.8 V to 5.5 V**
- **Low Noise: 14 nV/√Hz at 1 kHz**
- **Gain Bandwidth: 3 MHz**
- **Low Input Bias Current: 0.2 pA**
- **Low Offset Voltage: 0.5 mV**
- **Unity-Gain Stable**
- **Internal RF/EMI Filter**
- **Extended Temperature Range: –40°C to +125°C**

APPLICATIONS

- **Battery-Powered Instruments:**
  - **Consumer, Industrial, Medical**
  - **Notebooks, Portable Media Players**
- **Photodiode Amplifiers**
- **Active Filters**
- **Remote Sensing**
- **Wireless Metering**
- **Handheld Test Equipment**

DESCRIPTION

The OPA314 family of single-, dual-, and quad-channel operational amplifiers represents a new generation of low-power, general-purpose CMOS amplifiers. Rail-to-rail input and output swings, low quiescent current (150 µA typ at 5.0 V_S) combined with a wide bandwidth of 3 MHz, and very low noise (14 nV/√Hz at 1 kHz) make this family very attractive for a variety of battery-powered applications that require a good balance between cost and performance. The low input bias current supports applications with mega-ohm source impedances.

The robust design of the OPA314 devices provides ease-of-use to the circuit designer: unity-gain stability with capacitive loads of up to 300 pF, an integrated RF/EMI rejection filter, no phase reversal in overdrive conditions, and high electrostatic discharge (ESD) protection (4-kV HBM).

These devices are optimized for low-voltage operation as low as +1.8 V (±0.9 V) and up to +5.5 V (±2.75 V), and are specified over the full extended temperature range of –40°C to +125°C.

The OPA314 (single) is available in both SC70-5 and SOT23-5 packages. The OPA2314 (dual) is offered in SO-8, MSOP-8, and DFN-8 packages. The quad-channel OPA4314 is offered in a TSSOP-14 package.

ELECTRICAL CHARACTERISTICS: V_S = +1.8 V to +5.5 V(1)

Boldface limits apply over the specified temperature range: **T_A = –40°C to +125°C**.
At T_A = +25 °C, R_L = 10 kΩ connected to $V_S/2$, V_{CM} = $V_S/2$, and V_{OUT} = $V_S/2$, unless otherwise noted.

PARAMETER		TEST CONDITIONS	OPA314, OPA2314, OPA4314 MIN	TYP	MAX	UNIT
OFFSET VOLTAGE						
V_{OS}	Input offset voltage	V_{CM} = (V_S+) – 1.3 V		0.5	2.5	mV
dV_{OS}/dT	**vs Temperature**			**1**		**μV/°C**
PSRR	vs power supply	V_{CM} = (V_S+) – 1.3 V	78	92		dB
	Over temperature		**74**			**dB**
	Channel separation, dc	At dc		10		μV/V
INPUT VOLTAGE RANGE						
V_{CM}	Common-mode voltage range		(V–) – 0.2		(V+) + 0.2	V
CMRR	Common-mode rejection ratio	V_S = 1.8 V to 5.5 V, (V_S–) – 0.2 V < V_{CM} < (V_S+) – 1.3 V	75	96		dB
		V_S = 5.5 V, V_{CM} = –0.2 V to 5.7 V(2)	66	80		dB
	Over temperature	**V_S = 1.8 V, (V_S–) – 0.2 V < V_{CM} < (V_S+) – 1.3 V**	**70**	**86**		**dB**
		V_S = 5.5 V, (V_S–) – 0.2 V < V_{CM} < (V_S+) – 1.3 V	**73**	**90**		**dB**
		V_S = 5.5 V, V_{CM} = –0.2 V to 5.7 V(2)	**60**			**dB**
INPUT BIAS CURRENT						
I_B	Input bias current			±0.2	±10	pA
	Over temperature				**±600**	**pA**
I_{OS}	Input offset current			±0.2	±10	pA
	Over temperature				**±600**	**pA**
NOISE						
	Input voltage noise (peak-to-peak)	f = 0.1 Hz to 10 Hz		5		μV_{PP}
e_n	Input voltage noise density	f = 10 kHz		13		$nV/\sqrt{Hz}$
		f = 1 kHz		14		$nV/\sqrt{Hz}$
i_n	Input current noise density	f = 1 kHz		5		$fA/\sqrt{Hz}$
INPUT CAPACITANCE						
C_{IN}	Differential	V_S = 5.0 V		1		pF
	Common-mode	V_S = 5.0 V		5		pF
OPEN-LOOP GAIN						
A_{OL}	Open-loop voltage gain	V_S = 1.8 V, 0.2 V < V_O < (V+) – 0.2 V, R_L = 10 kΩ	90	115		dB
		V_S = 5.5 V, 0.2 V < V_O < (V+) – 0.2 V, R_L = 10 kΩ	100	128		dB
		V_S = 1.8 V, 0.5 V < V_O < (V+) – 0.5 V, R_L = 2 kΩ(2)	90	100		dB
		V_S = 5.5 V, 0.5 V < V_O < (V+) – 0.5 V, R_L = 2 kΩ(2)	94	110		dB
	Over temperature	**V_S = 5.5 V, 0.2 V < V_O < (V+) – 0.2 V, R_L = 10 kΩ**	**90**	**110**		**dB**
		V_S = 5.5 V, 0.5 V < V_O < (V+) – 0.2 V, R_L = 2 kΩ		**100**		**dB**
	Phase margin	V_S = 5.0 V, G = +1, R_L = 10 kΩ		65		deg

APPENDIX D

Blood Pressure Sensor Arduino Code Program (CryNet_Biomed)

CryNet_BioMed | Arduino 1.0.5

File Edit Sketch Tools Help

CryNet_BioMed

```
// CryNet_1 - based on Mark_18 for Andon Cuff

int pressureSensor = 0;
int airValve = 6;
int airPump = 7;
int button = 8;
int DIP1 = 9;  //for select maximum inflation
int DIP2 = 10;  //for select maximum inflation
int prog;
int state;
int DIP_1;
int DIP_2;
int maxS;  //set maximum inflation
int i;  //for array
int cnt;  //for counting beats for diastolic
float initial;
float x1;
float x2;
float x3;
float xS31;  //3 points moving average
float xS32;  //3 points moving average
float xC;  //changes between past and current reading
float xR1;  //rise value
float xR2;  //rise value
float xP;  //peak value
float xPR1;  //peak_real, previous value
float xPR2;  //peak_real, current value
float SPeak;  //significant peak value
float Systo;
float Diasto;
```

CryNet_BioMed | Arduino 1.0.5

File Edit Sketch Tools Help

CryNet_BioMed

```
unsigned long d;
unsigned long dx;

void setup()  {
  pinMode(button, INPUT);
  pinMode(airValve, OUTPUT);
  pinMode(airPump, OUTPUT);
  prog = 1;
  Serial.begin(9600);
  Serial.print("Collecting Data\n");
  Serial.print("Please Wait for a few moment");
  Serial.println("");
}

void loop()  {
  switch(prog)  {
    case 1:  //initial
    state = digitalRead(button);
    if (state == HIGH)  {
      Serial.print("----------------");
      delay(2000);
      Serial.println("");
      Serial.print("-----START!-----");
      delay(2000);
      Serial.println("");
      prog = prog + 1;
    }
    break;
```

CryNet_BioMed | Arduino 1.0.5

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CryNet_BioMed

```
    break;

    case 2:  //exceed Systolic
    x1 = analogRead(pressureSensor);
    initial = x1;
    // select maximum inflation
    DIP_1 = digitalRead(DIP1);
    DIP_2 = digitalRead(DIP2);
    if ((DIP_1 == LOW) && (DIP_2 == LOW))  {
      maxS = 650;  //about 150mmHg
    }
    if ((DIP_1 == LOW) && (DIP_2 == HIGH))  {
      maxS = 700;  //about 180mmHg
    }
    if ((DIP_1 == HIGH) && (DIP_2 == LOW))  {
      maxS = 750;  //about 210mmhg
    }
    if ((DIP_1 == HIGH) && (DIP_2 == HIGH))  {
      maxS = 800;  //about 240mmHg
    }
    while(x1 < maxS)  {
      digitalWrite(airValve, HIGH);
      digitalWrite(airPump, HIGH);
      x1 = analogRead(pressureSensor);
    }
    digitalWrite(airPump, LOW);
    prog = prog + 1;
    break;
```

CryNet_BioMed | Arduino 1.0.5

File Edit Sketch Tools Help

CryNet_BioMed

```
    case 3:  //Check for stable value
    Serial.print("Stablizing...");
    Serial.println("");
    delay(40);  //avoid early fluctuati
    xS31 = 0;
    x1 = 0;
    x2 = analogRead(pressureSensor);
    delay(40);  //sampling at 25ms
    while(xS31 < (maxS - 50))  {  //the
      x3 = analogRead(pressureSensor);
      dx = millis();
      xS31 = (x1 + x2 + x3)/3;
      x1 = x2;
      x2 = x3;
      Serial.print(xS31,2);
      Serial.println("");
      d = 40 - (millis() - dx);  //samp
      delay(d);
    }
    prog = prog + 1;
    break;
```

CryNet_BioMed | Arduino 1.0.5

File Edit Sketch Tools Help

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CryNet_BioMed

```
case 4:  //Detecting Peak, store data for analysis
float Sys[100];
float sxP[100];
float xHP[100];
i = 0;
Serial.print("Peak Detection");
Serial.println("");
Serial.print("x");
Serial.print("\t");
Serial.print("sxP");
Serial.print("\t");
Serial.print("xHP");
Serial.println("");
xPR1 = 0;  //Initial value of peak_real, 0 means no peak
xHP[0] = 0;  //Initial value of highest_peak
Sys[0] = 0;
sxP[0] = 0;
i = i + 1;  //ready for next array
x3 = analogRead(pressureSensor);
dx = millis();
xS32 = (x1 + x2 + x3)/3;
xR1 = xS31 - xS32;
x1 = x2;
x2 = x3;
xS31 = xS32;
d = 40 - (millis() - dx);  //sampling at 25ms
delay(d);
while(xS32 > 450)  {  //Once the Systolic detected, go to "Diastolic"
  x3 = analogRead(pressureSensor);
```

CryNet_BioMed | Arduino 1.0.5

File Edit Sketch Tools Help

CryNet_BioMed

```
    x3 = analogRead(pressureSensor);
    dx = millis();
    xS32 = (x1 + x2 + x3)/3;  //smoothing
    x1 = x2;
    x2 = x3;
    xC = xS32 - xS31;  //the change/difference betweem current and previous
    if(xR1 < 0)  {
      xR2 = xC;  //forming oscillation
    }
    else  {
      xR2 = xR1 + xC;  //forming oscillation
    }
    if ((xR1 >= 0) && (xR2 >= 0))  {
      if (xR1 >= xR2)  {
        xP = xR1;  //detect peak value
      }
      else  {
        xP = 0;  //no peak detected
      }
    }
    if ((xP <= 0) && (xPR1 <= 0))  {
      xPR2 = 0;  //no peak_real
    }
    if ((xP <= 0) && (xPR1 > 0))  {
      xPR2 = 0;  //no peak_real
    }
    if ((xP > 0) && (xPR1 <= 0))  {
      xPR2 = xP;  //peak_real detected
    }
    if ((xP > 0) && (xPR1 > 0))  {

      xPR2 = xPR1;  //peak_real detected
    }
    //suspecting Sys, store Sys and peak
    if (xPR2 > xPR1)  {
      Sys[i] = xS32;
      Serial.print(Sys[i],2);
      Serial.print("\t");
      sxP[i] = xPR2;
      Serial.print(sxP[i],2);
      Serial.print("\t");
      // determine highest peak
      if (sxP[i] > xHP[(i-1)])  {
        xHP[i] = sxP[i];
      }
      else {
```

CryNet_BioMed | Arduino 1.0.5

File Edit Sketch Tools Help

New

CryNet_BioMed

```
      xHP[i] = xHP[(i-1)];
    }
    Serial.print(xHP[i],2);
    Serial.println("");
    xHP[(i-1)] = xHP[i];
    i = i + 1;
  }
  xS31 = xS32;
  xR1 = xR2;
  xPR1 = xPR2;
  d = 40 - (millis() - dx);  /.
  delay(d);
}
digitalWrite(airValve, LOW);
SPeak = xHP[(i-1)] * 0.318707;
Serial.print(Sys[(i-1)],2);
Serial.println("");
Serial.print(initial,2);
Serial.println("");
dx = millis();
prog = prog + 1;
```

CryNet_BioMed | Arduino 1.0.5

File Edit Sketch Tools Help

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CryNet_BioMed

```
case 5:  //for systolic and diastolic detection
Systo = 0;
i = 0;
Serial.print("SPeak");
Serial.print("\t");
Serial.print(SPeak,2);
Serial.println("");
while (Systo < 5)  {  //systolic
  if (sxP[i] > SPeak)  {
    Systo = (Sys[i] - initial) * 0.586135;
    Serial.print("Systolic pressure (mmHg)");
    Serial.print("\t");
    Serial.print(Systo, 2);
    Serial.println("");
  }
  i = i + 1;
}
Diasto = 0;
cnt = 0;
while (Diasto < 5)  {  //diastolic
  if ((sxP[i] < SPeak) && (xHP[i] > SPeak))  {
    cnt = cnt + 1;
  }
  else  {
    cnt = 0;
  }
  if (cnt > 3)  {
    Diasto = (Sys[(i-4)] - initial) * 0.586135;
    Serial.print("Diastolic pressure (mmHg)");
    Serial.print("\t");
     }
     i = i + 1;
   }
   delay(3000);
   Serial.print("Done...");
   Serial.println("");
   Serial.println("");
   prog = prog - 4;
   break;

   default:
   digitalWrite(airValve, HIGH);
   digitalWrite(airPump, LOW);
   delay(50);
   digitalWrite(airValve, LOW);
   digitalWrite(airPump, LOW);
   delay(50);
   digitalWrite(airValve, LOW);
   digitalWrite(airPump, HIGH);
   delay(50);
   digitalWrite(airValve, LOW);
   digitalWrite(airPump, LOW);
  }
```