DEVELOPING CONTINUOUS REMOTE BLOOD PRESSURE MONITORING SYSTEM

By

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Final Year Project

Submission to the Department of Electrical & Electronic Engineering
in Partial Fulfilment of the Requirements for the Degree
Bachelor of Engineering (Hons)
(Electrical and Electronic Engineering)

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CERTIFICATION OF APPROVAL

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Approved:

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PETRONAS TRONOH, PERAK
August
2014

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.

Phisnukh Uttraphan A/L Pim

ABSTRACT

Normal method of monitoring the blood pressure is through manually measured by medical practitioners through the use of sphygmomanometers or automatically by blood pressure devices. These methods having drawbacks which might concur fatalities. Manual measurement is susceptible to human errors and environmental fluctuations.

High or low pressure during the time interval in which the medical practitioners did not measure the pressure might not be administered in the treatment of the patient meaning there is a gap in data which might lead to misdiagnosis. Wireless System module is been used to obtain the objective of this project in which desirably a wireless monitoring system is designed.

CHAPTER 1
INTRODUCTION

1. BACKGROUND

The most widely used blood pressure monitoring system currently is the electronic version of Oscillometric blood pressure device. The readings of blood pressure is done automatically with the device which is better than two of its older counterparts which are the sphygmomanometers and the Korotkoff method. The three aforementioned devices have their biggest flaw which is not being able to be operated without manual observation by the medical personnel. This is highly disadvantageous in the advent that the spike in blood pressure occurs during the personnel off time or the time interval between each checks which may lead to complications or even increasing the patients' mortality rate.

This project is to further improve the electronic version of Oscillometric blood pressure device by enabling it to be monitored remotely from a workstation. The general overview of this project is to have the computer receiving the readings from the sensors equipped on a patient. Without having to be physically present by the patient's side, medical personnel would be able to monitor the blood pressure of the said patient. Further modifications to the system are the alarm system to alert medical personnel of the patient's need for immediate care and be able to record the findings from the device.

2. PROBLEM STATEMENT

There are several issues with the current technology and system that is being used in medical practices;

(a) The danger in which medical personnel might overlook a certain spike in blood pressure during each measuring intervals.
(b) Due to the present one being semi-automated, there is a need for a medical staff to be present by the patient's side to record the blood pressure readings.

With this project in its initial stage, the author is hoping to overcome the aforementioned issues by having the device monitoring the patient continuously and alerting the medical practitioner workstation if the if there is a drop below or spike above the predefined limits of both systolic and diastolic levels.

3. OBJECTIVES & SCOPE OF STUDY

The objectives on the mind of the author on this project are clear and simple, aiming towards obtaining the solutions to tackle the problems stated earlier by the author. The objectives are:

(a) While displaying the blood pressure readings on the panel or screen, the device should be able to detect patient's systolic and diastolic levels automatically and continuously.
(b) To be able to transmit the blood pressure readings (data) wirelessly by incorporating wireless system and send the data to the medical practitioner desk and alerting them when the predefined limits of the readings are exceeded.

CHAPTER 2

LITERATURE REVIEW

1. INTRODUCTION

The author decided to have a generalized overview of blood pressure in the literature review. The general overview of blood pressure would include Zigbee wireless system, systolic and diastolic pressure, and the boon of having high blood pressure and the available devices on the market.

2. Theory and Background Studies

2.1 Blood Pressure Overview

Definition wise, blood pressure is the ability or the strength (pressure) of the heart in pumping blood through the arteries, circulating it throughout the whole blood circulation system. The beating of human's heart is approximately 60 to 100 beats per minute which enabling the blood to be pumped, thus oxygen and energy required by the human can be distributed throughout the entire body [1].

Mean artery pressure, diastolic and systolic pressure are the 3 major components of blood pressure measurements. Millimeter of mercury (mmHg) is the unit used whereby healthy individuals usually having approximately 90mmHg for mean artery pressure, ≤ 80mmHg for diastolic pressure and ≥ 120mmHg systolic pressure. One of the main indicators of one's general wellness is through blood pressure [1].

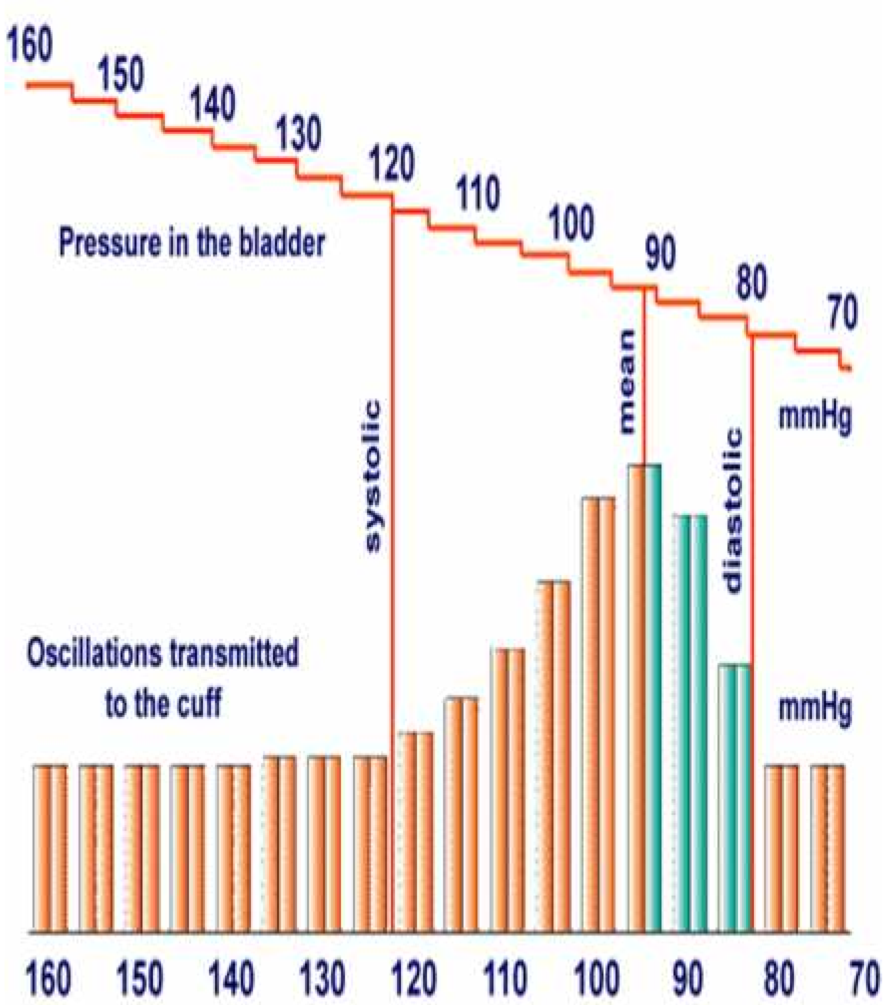

Figure 1 : Oscillometricss principle

Age	Range	Systolic (mmHg)	Diastolic (mmHg)	Median Normal Systolic/Diastolic (mmHg)
15 to 19	Minimum	105	73	105/73
	Average	117	77	117/77
	Maximum	120	81	120/81
20 to 24	Minimum	108	75	108/75
	Average	120	79	120/79
	Maximum	132	83	132/83
25 to 29	Minimum	109	76	109/76
	Average	121	80	121/80
	Maximum	133	84	133/84
30 to 34	Minimum	110	77	110/77
	Average	122	81	122/81
	Maximum	134	85	134/85
35 to 39	Minimum	111	78	111/78
	Average	123	82	123/82
	Maximum	135	86	135/86
40 to 44	Minimum	122	79	122/79
	Average	125	83	125/83
	Maximum	137	87	137/87
45 to 49	Minimum	115	80	115/80
	Average	127	84	127/84
	Maximum	139	88	139/88
50 to 54	Minimum	116	81	116/81
	Average	129	85	129/85
	Maximum	142	89	142/89
55 to 59	Minimum	118	82	118/82
	Average	131	86	131/86
	Maximum	144	90	144/90
60 to 64	Minimum	121	83	121/83
	Average	134	87	134/87
	Maximum	147	91	147/91

Table 1 : Blod pressure chart according to age group

The Oscillometric methods are being compared in [2] to other types of blood pressure measuring device for example with Korotkoff methods. Oscillometric method utilizes the pumping of air pressure into the cuff wrist which will tighten, stopping blood circulation in the process. Then, the cuff wrist will loosen its grip on the wrist slowly when the pressure is released. The device measures the blood pressure electronically throughout the deflation and inflation phase before estimating the systolic and diastolic by means of properties of algorithm.

However, Oscillometric do has it weaknesses both internally and externally. Externally, the unpredictability in measurements is due to the patient's arm position throughout the test and the physical wellbeing of the patoent during the test. Internally, due to the lack in calibration of air pressure sensors and its system, and also the lacking in the diastolic and systolic pressure estimation algorithm [2].

Represented on the graphical waveform is the digitized value of the blood pressure readings as the oscillometric methods used a mathematical algorithm in measuring blood pressure. From the waveform, two distinguished peak is analyzed where by first peak is the systolic peak (inflation phase) and the second peak being the diastolic peak (deflation phase).

The oscillometric morphology method estimates systolic pressure (SBP) and diastolic pressure (DBP) through signal-based approach which in turns deriving a method to do an estimation of mean arterial pressure (MAP) [3]. * MAP = DBP + 1/3 (SBP-DBP)

As been required by the recommendations from Association for Advancement of Medical Instrumentation – AMMI , the mean difference for systolic was ± 5mmHg and diastolic was ±8 mmHg [4].

Figure 2 : Riva-Rocci's sphygmomanometer of 1869 through palpation

Figure 3 : Modern type of Clinical Mercury Sphygmomanometer

2.1.1 Integration of Electronic Blood Pressure Monitor with Computer through wireless means

Expected system designed is a monitoring system of blood pressure which is capable of sending data to a remote computer or console to be used for remote usage of the system. The communication of the blood pressure with the console or the computer can be done by several methods which will be discussed by the author later on.

Thinking of transmission of data from a group of people with their data of blood pressure needing identification which reflects a certain person of said group. Firstly, RFID or Radio Frequency Identification method is identified as a plausible method for this. This method allows certain tag or subject which could identify its identity automatically. RFID could be divided into 2 which are the active RFID tag and the passive RFID tag. Active RFID tag is identified as a tag in which has battery as its' internal source of power. However, passive RFID is being powered externally through the means of external source or RFID reader. Communication range wise, active RFID has a wider range of communication comparing to that of the passive one. However, active RFID tag does need the inclusion of internal battery source which leads to it having a shorter time span of usage compared to the passive ones. This problem can be solved. Hence, the one more suitable for usage is active RFID [**8**] [**9**].

However, through the disadvantages encountered when using the RFID leads the author to find another solution for this wireless communication which is through the usage of ZigBee technology which is the communication between nodes wirelessly, allowing for the computer or console to share information with other computers within the range of wireless personal area network (WPAN). Its low power consumption coupled with its simplicity leads to the author moving towards this technology. Zigbee is coupled with the Arduino and will be further discussed by the author later on.

Figure 4 : Active RFID

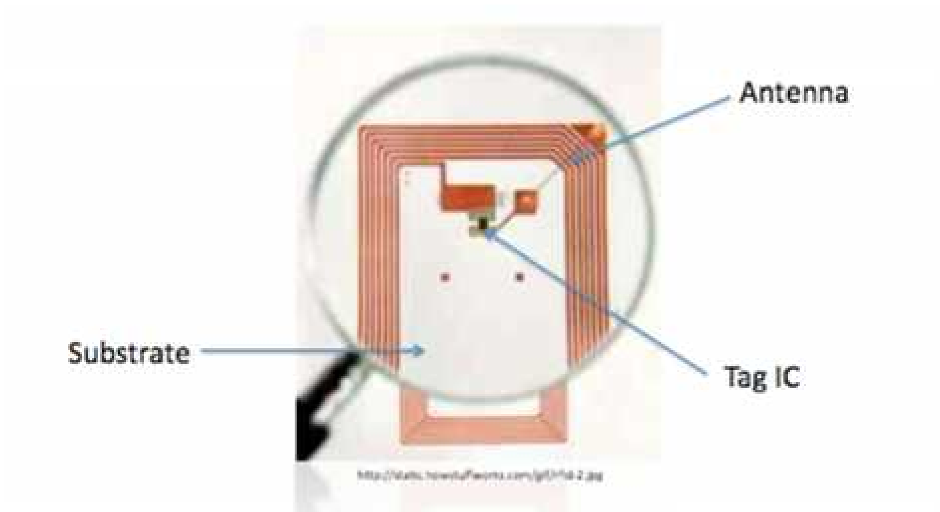

Figure 5 : Passive RFID

Figure 6 : ZigBee wireless module

2.2 Literature Review

In this subsection, it is divided into two, namely wireless technology and blood pressure measurement papers.

2.2.1 Wireless Technology papers

There are a number of researchers whom contributed in various studies concerning the study if bio-medical engineering field. One of them is done by Yuan-Hsiang Lin, Wun-Jin Li, Yao-Shun Chang and Yuan-Long Luo (2010). They did invented a monitoring system of blood pressure wirelessly consisting of a computer and a BP monitor. The ARM controller is being the base of the BP monitor whereas Zigbee is being the base of data transmission. The line chart is being portrayed for the user to analyze the blood pressure variation. This system is very convenient in the usage for health management personally. [**17**]

Another study related to wireless technology was done by Maria Rodriguez-Moreno and Bonifacio Castano (2011). Their study was related to the usage of hybrid of RFID and Zigbee. The system which relies on the hybrid of those two is able to bne use for monitoring of movements if people inside a building. The system could be used to generate data on the movements of people in which it will be used for increasing the attractiveness of an exhibition by the management team of the building. This system is consisted of RFID detector, RFID tags and the network topology of Zigbee [**11**].

The usage of active RFID tags is power consuming but this problem is olved by a study done by Jie Jin and Qingbin Meng (2011) which suggested on lower consumption by the active RFID tags. Their prototype consist of microcontroller, battery, antenna and co-processing digital circuit transceiver. The co-processing digital circuit is used to block incorrect received information to ensure microcontroller stays in sleep mode which in turns lowers power consumption [9].

The project done by the author is quite similar to that done by Yuan-Hsiang Lin, Yao-Shun Chang and Yuan-Long Luo (2011). The difference with this project is that, this project has multiples blood pressure sensors and tags. Instead of one way, multiple ways into a single computer is used [**17**].

This project, Arduino board is being used as controller of the project. Hence, Zigbee module is used with Arduino board [**10**].

2.2.2 Blood Pressure Measurement relevance papers

Development of a real-time blood pressure monitoring system is a currently a trending research area, where continuous measurements are done and patients are notified of any abnormal BP readings. However, current BP measurement methods such as the oscillometric method and the standard auscultatory method using mercury sphygmomanometer are still not robust enough.

One BP measurement technique is the PTT technique. A controlled clinical trial on the reliability of the PTT technique was carried out by C Dounima, CU Sauter, and R Couronne (2009). This trial involved taking measurements from 22 sedated patients, however only 14 were found to be suitable for analysis. The data represented over 240 hours of measurements using pairs of vital signals. The signals measured in this research are were electrocardiogram (ECG), bioimpedence plethysmogram (IPG), invasive blood pressure (IBP),bioimpedence cardiogram (ICG) and photoplethysmogram (PPG). From this research it has been found that the smallest average error is 4.91 mmHg, between the ECG and IBP pair. The results unfortunately demonstrated that the PTT technique is unreliable for BP measurement.

Research conducted by M K Ali Hassan, M Y Mashor, A R Mohd Saad, and M S Mohamed (2011) concerned the development of a portable BP measurement kit. A set of BP measurement data are taken by the mercury sphygmomanometer method as reference data for the kit, which implemented BP monitoring based on a neural network model. The collected data are ECG and BP signals taken from 20 subjects (15 to 60 years old), which are then used to train the kit's neural network algorithm. From this study it has been found that while this measuring kit delivers somewhat accurate BP measurement, improvements can be done to reduce the average error of -0.4712 mmHg, with a standard deviation of 2.204 mmHg.

A variant of the PTT technique was tested in a study conducted by Heiko Gesche, Detlet Grosskurth, Gert Kuchler and Andreas Patzak (2011). The objective of this research was to establish a relationship between systolic BP and Pulse Wave Velocity (PWV), and to use the resulting function in an improved BP measurement technique. The PWV,which is produced by ECG and PPG was obtained via PTT. A group of volunteers were required to ride on a bicycle ergo meter with varying loads. Measurements were conducted on 63 volunteers, and the resulting data from 13 individuals are used in the subsequent analysis. This research found that there exists a significant relationship between PWV and systolic BP. However a recorded error of 20 mmHg means that this method still needs to be refined.

Another real-time BP monitoring system is developed by Md Manirul Islam, Fida Hasan Md Rafi, Abu Farzan Mitul, Mohiuddin Ahmad, M A Rashid, and Mohd

Fareq bin Abd Malek (2012), this time by implementing the PPG technique. In this technique, a Light Emitting Diode (LED) and Light Dependent Resistor (LDR) are attached to the opposite sides of a finger. This method works by exploiting the fact that the flow of blood through the artery is maximum during the systolic cycle, thus reducing the light received by the LDR from the LED. The converse is true during the diastolic cycle, when the light received by the LDR is maximum. A weakness of this system is that it needs to be recalibrated for each person. This is due to different finger and artery sizes for each individual. The recorded error is also relatively large compared to mercury sphygmomanometer, about 4mmHg.

In conclusion, the most feasible method of BP measurement to be implemented in this project is the oscillometric method. The complexity of the other real-time BP measurement techniques also make them less suitable for this project.

CHAPTER 3

METHODDOLOGY

3.1 METHODOLOGY

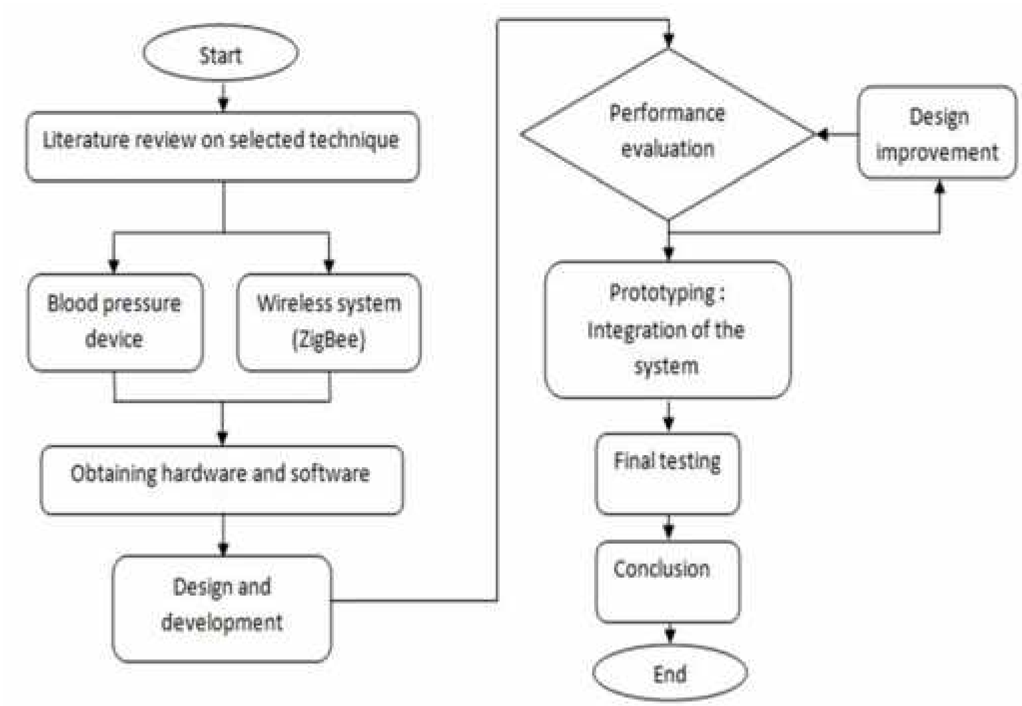

Figure 7 : Methodology Flow Chart

Detail / Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Topic of Project Selection														
Preliminary Research Work														
Submission of Extended Proposal														
Proposal Defense														
Continue Project Work														
Submission of Interim Draft Report														
Submission of Interim Report														

Table 2 : FYP1 Gantt Chart

Detail / Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Further Research														
Components Testing														
Submission of Progress Report														
PresSedex Presentation														
Continue Project Work														
Latest Project Works														
Submission of Final Report														

Table 3 : FYP2 Gantt Chart

3.2 Support Tools

Several important tools are used in this project which are then dividen into softwares and hardwares.

No	Tools	Description
1	Electronic Pressure Gauge	For calibration of the designed BP sensor.
2	DC Power Supply	To supply DC voltage.
3	Digital Multimeter	To measure electrical parameters.

Table 4 : List of hardware tools and their description

No	Tools	Description
1	Open source Arduino Development software	For writing and compiling the programming codes. To upload the programming codes into Arduino board.
2	Microsoft Excel	For analysing the BP data and simulate the data before the programming codes is written.
3	Multisim	To simulate the electronic circuit design before the circuit is built.
4	Pspice	To simulate the electronic circuit design before the circuit is built.

Table 5: List of important softwares and their description

3.3 The Hardware Components

The main hardwares are listed and explained in this subsection.

3.3.1 Pressure Sensor

FIGURE 8 The MPX5700DP Pressure Sensor by Freescale Semiconductor, Inc.

Pressure sensor is for measuring air pressure inside the cuff. The exerted pressure is represented by quantifying the analogue electrical signal. Piezoresistive transducer is stretched due to the difference in pressure and in turns produces electrical signal by applying the bridge circuit principle [**18**].

Output of pressure sensor is amplify then filtered by the amplifier and low pass filter. The output of pressure sensor is minute (300 mmHg or 50kPa) hence needed amplification. Freeescale pressure sensor is able to do measurement of 0 kPa to 700 kPa,. Then signal is analysed as systolic and diastolic pressure by the microcontroller [**19**]

3.4.2 Motor Pump & Solenoid Air Valve

Motor pump is for increasing air pressure. Air valve is for holding air pressure inside the cuff. In the beginning the author intended to use 6 V of power supply. However, using Zigbee 5 V power supply only is needed due to usage of ZIgbee over RFID hence ensuring usage of only one power supply.

FIGURE 9 The motor pumps and air valve. 3VDC left 6 VDC right

3.4.3 Microcontroller

The author’s project use the ARduino Duemilanove as the controller which is using the base of Atmega 328 which has 14 I/O pins, 16 MHz oscillator , Usb connection, power jack, ICSP header, 6 analogue inputs and a reset button [10].

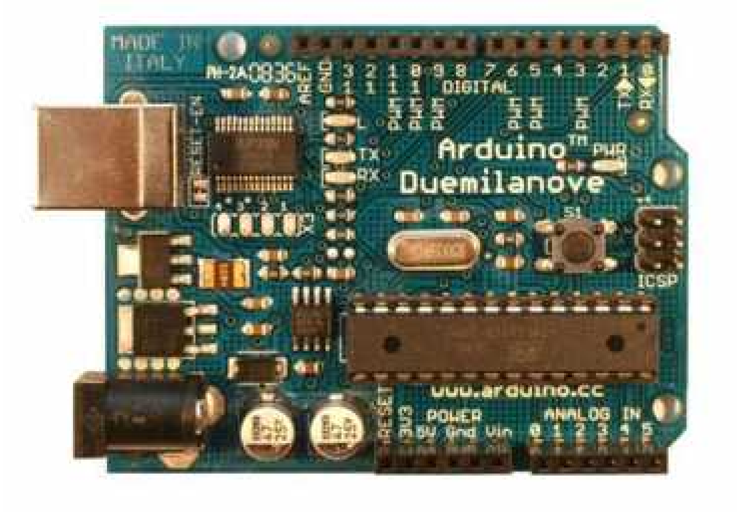

FIGURE 10 The Arduino Duemilanove board.

Chapter 4

Results & Discussion

Freescale pressure sensor, simple low pass filter circuit, amplifier circuit with LM 358 operational amplifier, motor pump, solenoid air valve, relays, 6V power supply and Arduino board is the make-up of the overall circuit. The circuit is connected to the computer via USB socket on Arduino board.

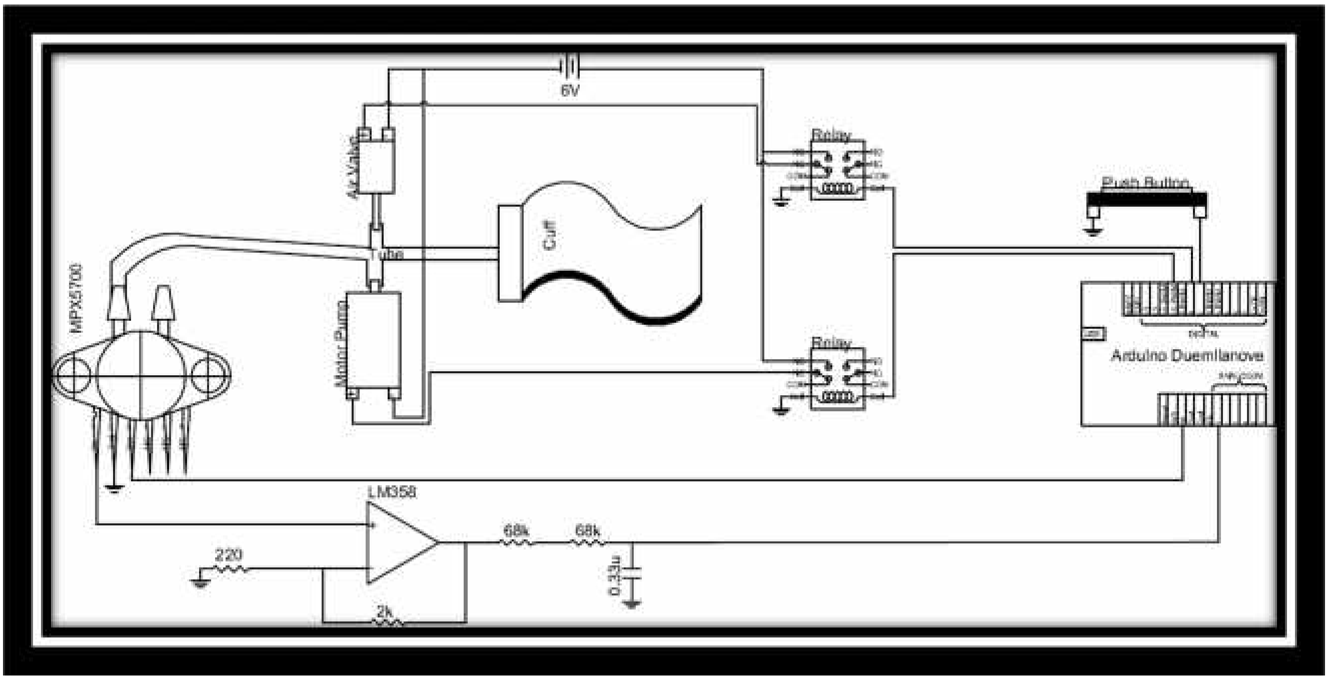

Figure 5 : Overall Circuit

A separated power supply of 6V is used to power the air valve and motor pump which are rated at 6V as the Arduino board only cater to 3.3 V and 5V.

Output signal which reflects upon the pressure inside the cuff is produced by the pressure sensor. The signal is amplified by the filter prior to interpretation by the Arduino.

Systolic and Diastolic pressure will be determined by the Arduino through its programming. The resulting data would be displayed in Arduino Serial Monitor.

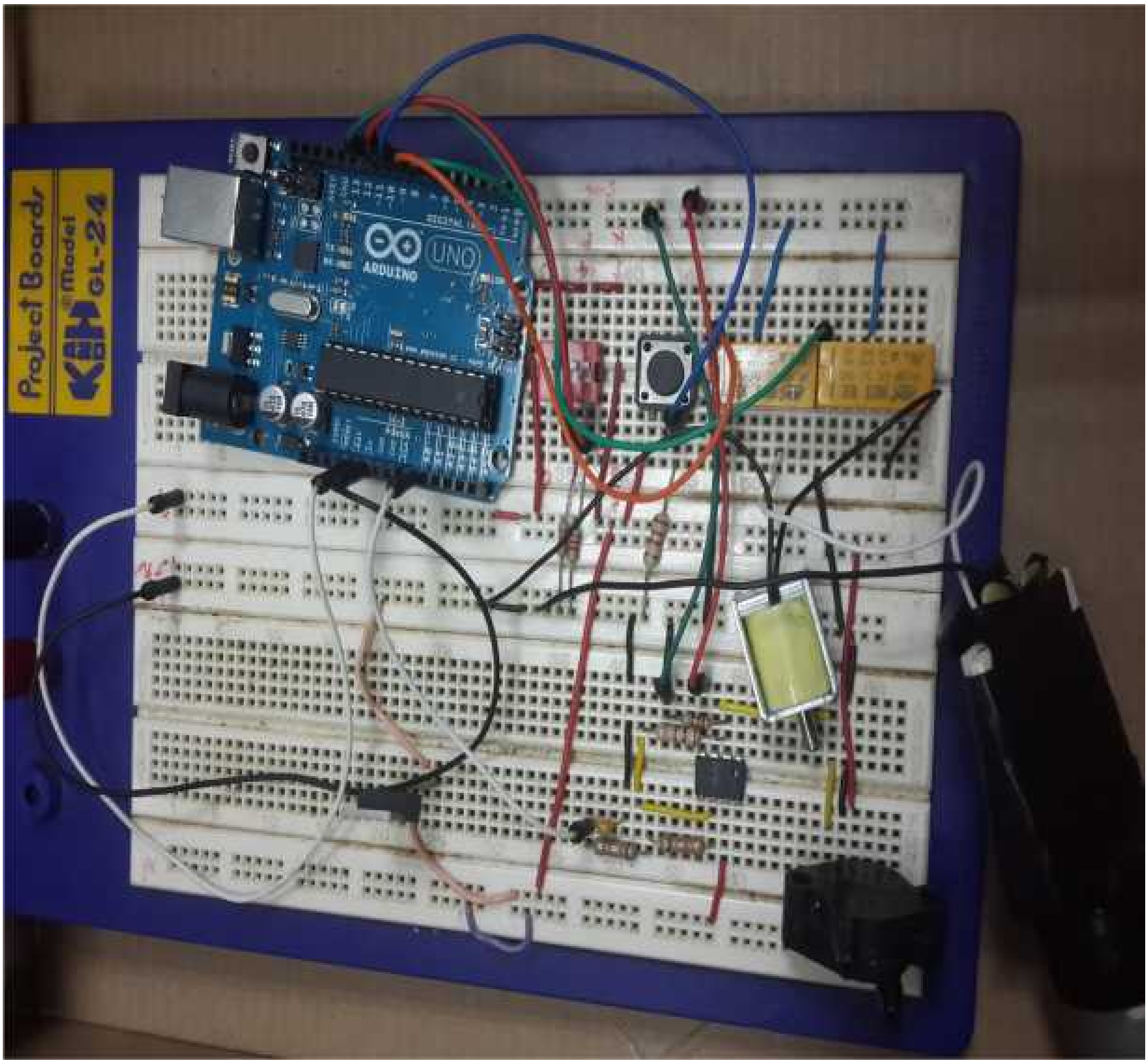

Figure 6: Current Circuit

The circuit is still missing the tubes to connect the pressure sensor with the motor pump and air valve as the author have not taken the tube from Miss Fauhana.

The whole of blood pressure monitoring system is controlled by the Arduino. Numerous programming codes have to be written to ensure suitability of programming codes to be used on the blood pressure level measurement process. It starts with motor pump inflating the cuff before stopping. The gradual deflation of the cuff is used in the determination of diastolic and systolic pressure. Air is released by the air valve after the deflation stage which in turns reduces the cuff pressure.

An analogue signal is received by the Arduino and it determines which pressure is diastolic and which is systolic pressure. Microcontrollers should be able to handle only digital signal however, Arduino does have ADC to quantize analogue signal into digital signal.

The digital signal needs some calibrations to represent the actual pressure readings. The digital signal is compared with the pressure gauge to obtain such result. The experiment is conducted multiple times.

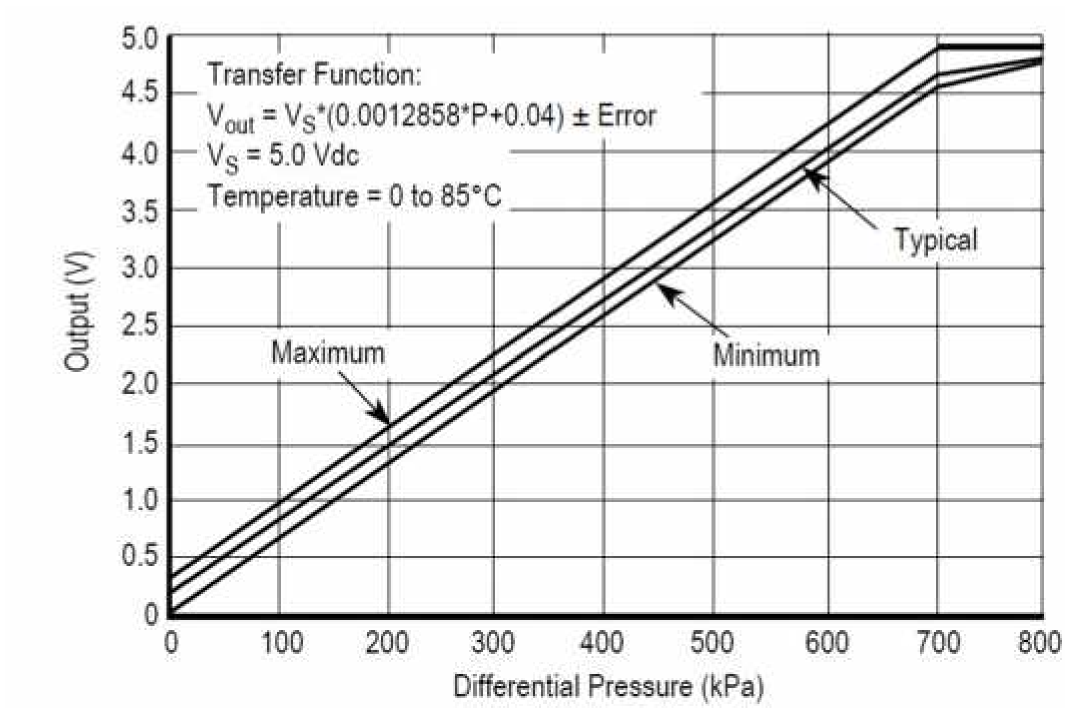

Figure 7: Output against Pressure Differential taken from the datasheet of MPX5700DP

Chapter 5

CONCLUSION & RECOMMENDATION

The project might not be realised as a complete system (with prototype) in the time frame. But it is possible to be done to fulfil both objectives (the project will not be prototyped).

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APPENDICES

```
// Mark_18 - based on Mark_11 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;
unsigned long d;
unsigned long dx;
```

```
void setup()  {
  pinMode(button, INPUT);
  pinMode(airValve, OUTPUT);
  pinMode(airPump, OUTPUT);
  prog = 1;
  Serial.begin(9600);
  Serial.print("Annyeong haseyo!");
  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;

    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;

    case 3:  //Check for stable value
    Serial.print("Stablizing...");
    Serial.println("");
    delay(40);  //avoid early fluctuation
    xS31 = 0;
    x1 = 0;
    x2 = analogRead(pressureSensor);
    delay(40);  //sampling at 25ms
    while(xS31 < (maxS - 50))  {  //the smoothing value must exceed (maxS
50)
      x3 = analogRead(pressureSensor);
      dx = millis();
      xS31 = (x1 + x2 + x3)/3;
      x1 = x2;
      x2 = x3;
      Serial.print(xS31,2);


  Serial.println("");
  d = 40 - (millis() - dx);  //sampling at 40ms
  delay(d);
}
prog = prog + 1;
break;

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);
  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 {
     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);  //samping at 40ms
 delay(d);
}
digitalWrite(airValve, LOW);
SPeak = xHP[(i-1)] * 0.318707;  //determine significant peak
Serial.print(Sys[(i-1)],2);
Serial.println("");
Serial.print(initial,2);
Serial.println("");
dx = millis();
prog = prog + 1;
break;

  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");
      Serial.print(Diasto, 2);
      Serial.println("");
```

```
      }
      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);
  }
}
```