Automated Blood Pressure Measuring System

This project aims to design and build an **Automated Blood Pressure Measuring System**, henceforth called **BPMD**, that can measure the user's systolic & diastolic blood pressure and heart rate using an inflatable arm cuff. The device consists of 3 parts: external systems, analog circuits, and a microcontroller.

Advantages of BPMD over other methods:

This **BPMD** is based on the **oscillometric method** of measuring blood pressure as opposed to the **auscultatory method**. The digital oscillometric method is much more efficient than the mercury sphygmomanometer taking into account the time taken to train professionals to use the latter properly and the human error that can be introduced while taking the reading. Also, the time taken to measure the blood pressure is reduced significantly though there are errors introduced due to transducers and the other components.

Parts of BPMD:

The **External System** which includes the motors, valves, and arm cuff allows us to measure the blood pressure (both systolic and diastolic) by sensing the changes in pressure in the arm cuff after being inflated to the appropriate pressure level.

The **Analog Circuitry** which includes amplifiers and filters is used to convert the pressure value from the cuff into usable, readable analog waveforms that can be used for further operations. These circuits are designed keeping in mind the output voltage range of the pressure transducer and the input voltage level of the microcontroller.

The **Microcontroller Unit** controls the operation of the device, and samples, and converts the analog signal to a digital signal that can be used to perform further operations to obtain blood pressure and heart rate values using inbuilt algorithms.

Measurement of blood pressure:

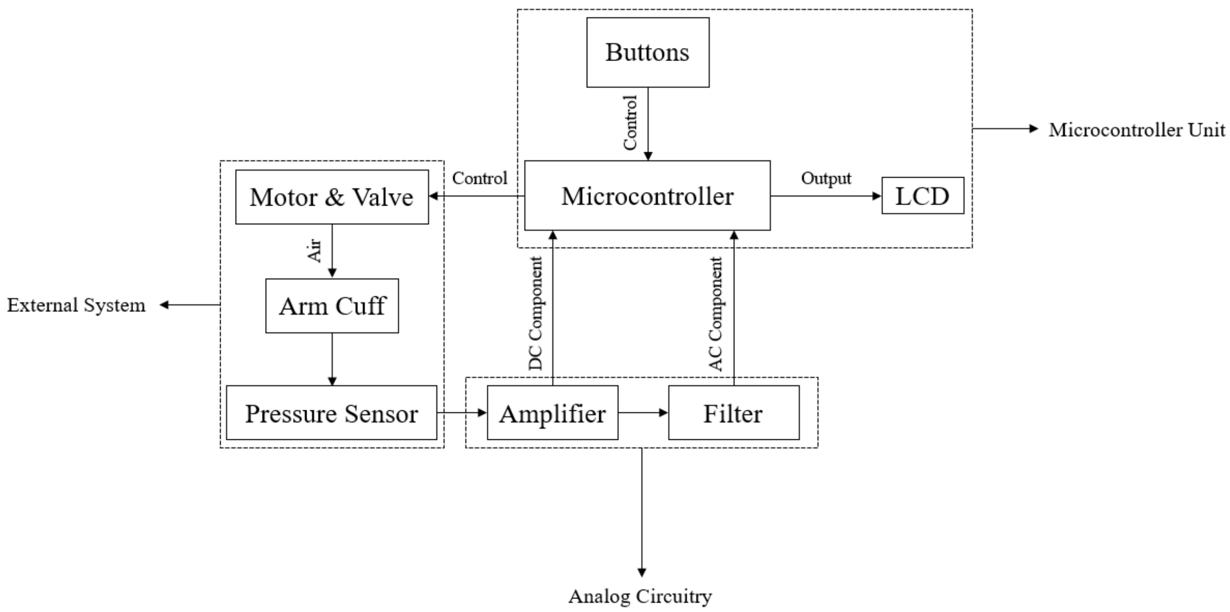
In the auscultatory sphygmomanometer,

First, the cuff is inflated to a pressure above the known systolic pressure (around 120 mmHg), i.e., around 140 mmHg. Then the air in the cuff is slowly reduced, i.e., the pressure is reduced slowly so that the sound of a heartbeat is audible. This is the Korotkoff phase I sound which is indicated by 2 consecutive clear tapping sounds which denote the introduction of blood flow under the cuff (i.e., systolic pressure). As the pressure continuously decreases at some point the sounds will disappear, which denotes the Korotkoff phase V sound that indicates the complete unrestricted flow of blood under the cuff (i.e., diastolic pressure).

In the oscillometric automated BPMD,

First, the cuff is inflated to a pressure above the known systolic pressure (around 120 mmHg), i.e., around 140 mmHg. Then the air in the cuff is slowly reduced. As the pressure continuously decreases, we constantly measure the tiny oscillations in the air pressure of the cuff. The systolic pressure will be the pressure at which the pulsation starts to occur. We then use the microcontroller to detect the point at which this oscillation happens and then record the pressure in the cuff. Then the pressure in the cuff will decrease further. The diastolic pressure will be taken at the point at which the oscillation starts to disappear.

<u>Block diagram of the BPMD:</u>



<u>Explanation of blocks:</u>

In the Microcontroller Unit, the microcontroller takes input from the pressure sensor through the analog circuitry & the ADC and performs operations on it to find the systolic and diastolic pressure. It also controls the motor and valve which is used to inflate and deflate the cuff. This block aims to control the BPMD and process the signal to obtain appropriate values.

In the Analog Circuitry, we have the, amplifiers (including instrumentation amplifiers, etc.,), & filter circuits that amplify, filter, and separate the DC and AC components of the incoming signal. It gives the processed analog signal to the ADC in the microcontroller for conversion into a digital signal. This block aims to reduce the noise in the signal received from the pressure sensor for better output.

In the External System, the peripherals such as the motor, valve, and pressure sensor help us perform the necessary actions to obtain the blood pressure signal. The motor fills the air into the cuff and the inflation and deflation of the cuff are controlled by the valve based on the instruction from the microcontroller.

<u>Design of the BPMD:</u>

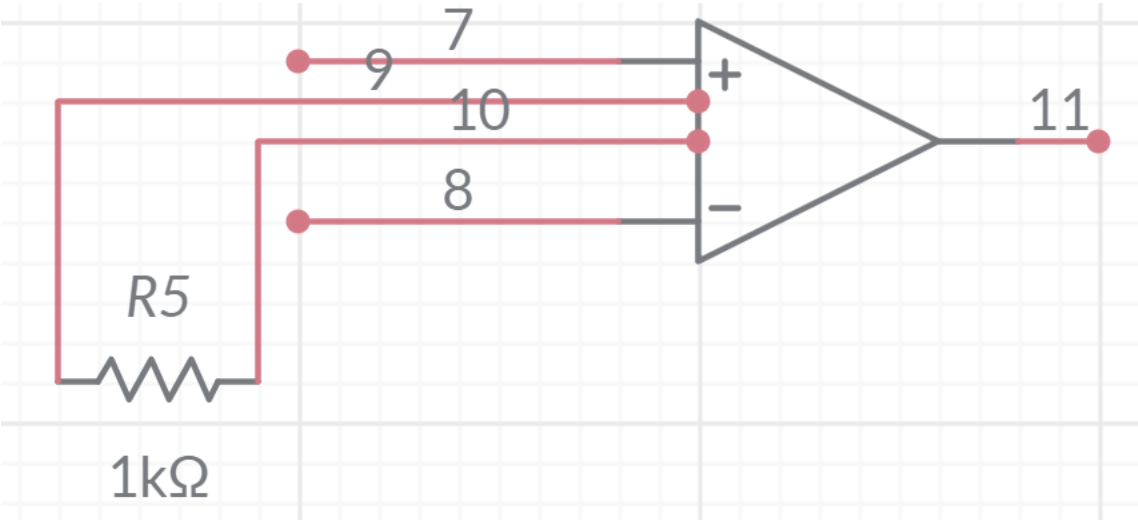
The analog circuitry is designed to reduce noise effectively and amplify the signal. The amplification of the circuit is decided by the value of the output voltage received from the pressure sensor. Also, the frequency of signals that are unnecessary in calculations is filtered out using a low-band pass filter.

The microcontroller contains algorithms derived from the Maximum Amplitude Algorithm (MAA) with pre-decided cutoff threshold values to obtain blood pressure values. The microcontroller consists of multiple functions that are sequentially performed. The ADC in the microcontroller is sampled at the necessary frequency to obtain values without any delay and error.

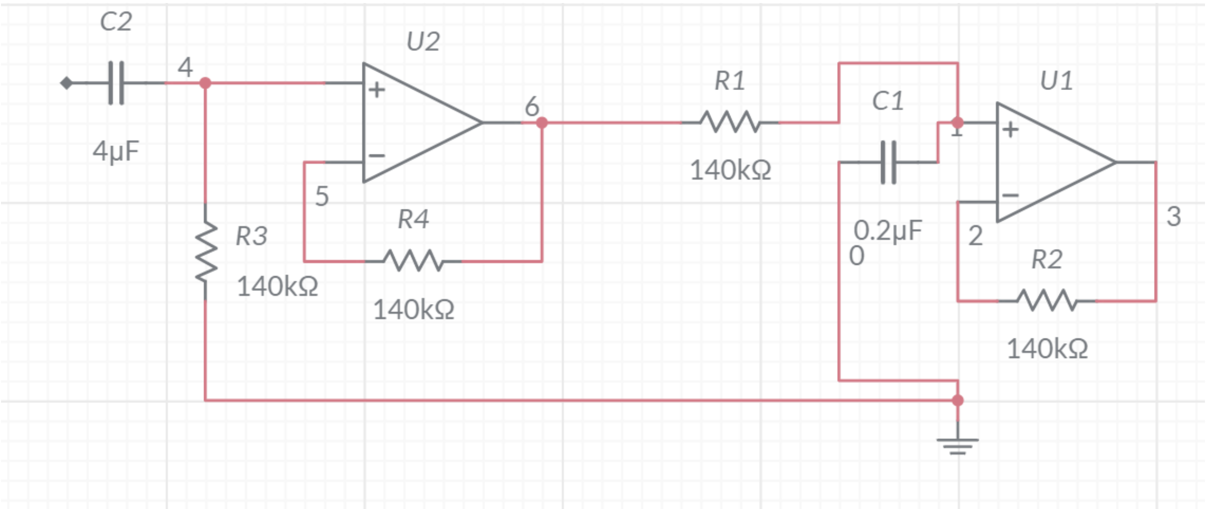
The external system with plays an important role in the measurement of blood pressure. An optimal inflation and deflation rate of 2-3 mmHg/s is recommended for obtaining proper signal waveforms from the pressure sensor. The major error in the measurement of BPMD is introduced while reading the signal values from the external system.

Analog Circuitry:

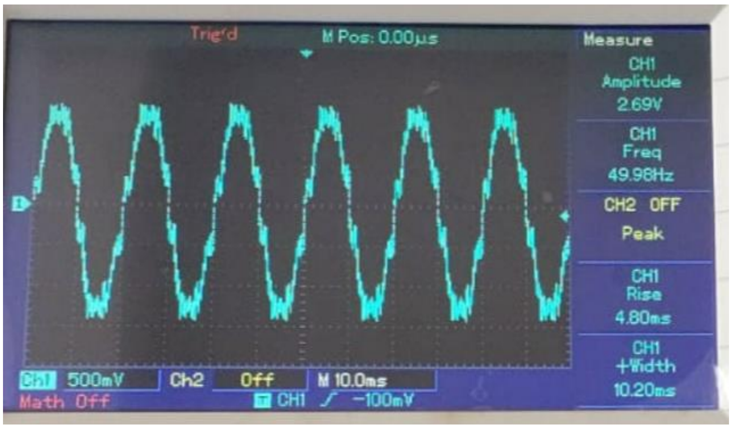
The analog circuit consists of an instrumentation amplifier, high pass filter and a low pass filter. The instrumentation amplifier is designed to have an amplification of 220. The instrumentation amplifier is capable of amplifying an 18mV signal to 4V.



This output is given a high pass filter with 0.3Hz as the cutoff. Then we cascade a low pass filter with 6Hz cutoff frequency.



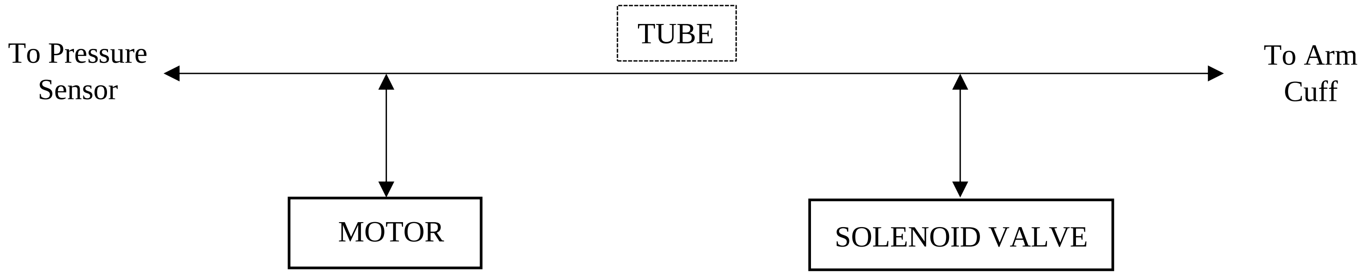
The output from the low pass filter is



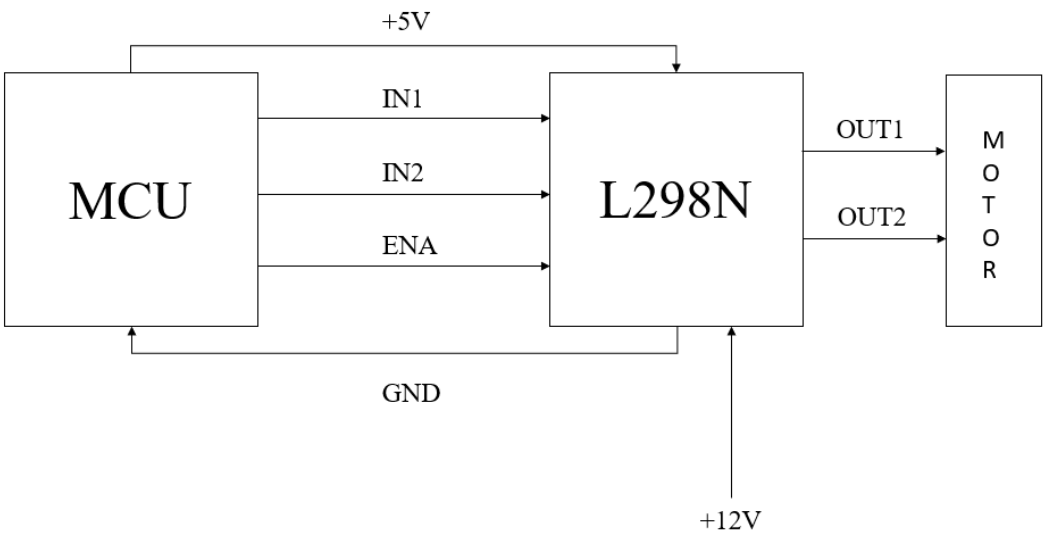
The above output is when the pressure sensor is exposed to air. When more pressure is applied the amplitude of the signal increases thus allowing us to calculate the blood pressure of the user. The noise due to the power supply can cause errors in the measurement but we can use better algorithms to reduce that error.

External System:

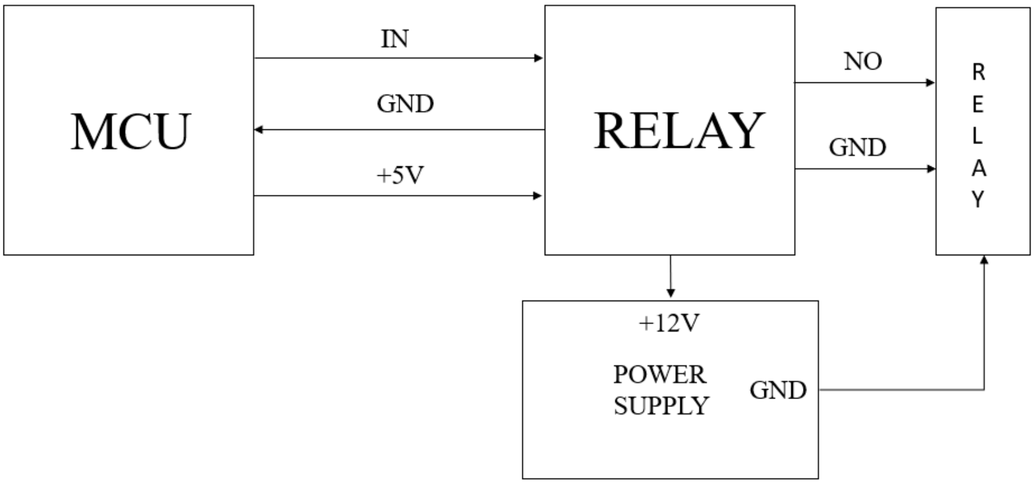
This system consists of the motor, solenoid valve, driver and solid-state relay. This system is essential for the inflation and deflation of the arm cuff to enable pressure measurement.



Motor, also called the air pump motor is used to pump the air to the cuff. It requires 12V DC supply to run and pump the air. The motor is connected to the microcontroller through the L298N driver.



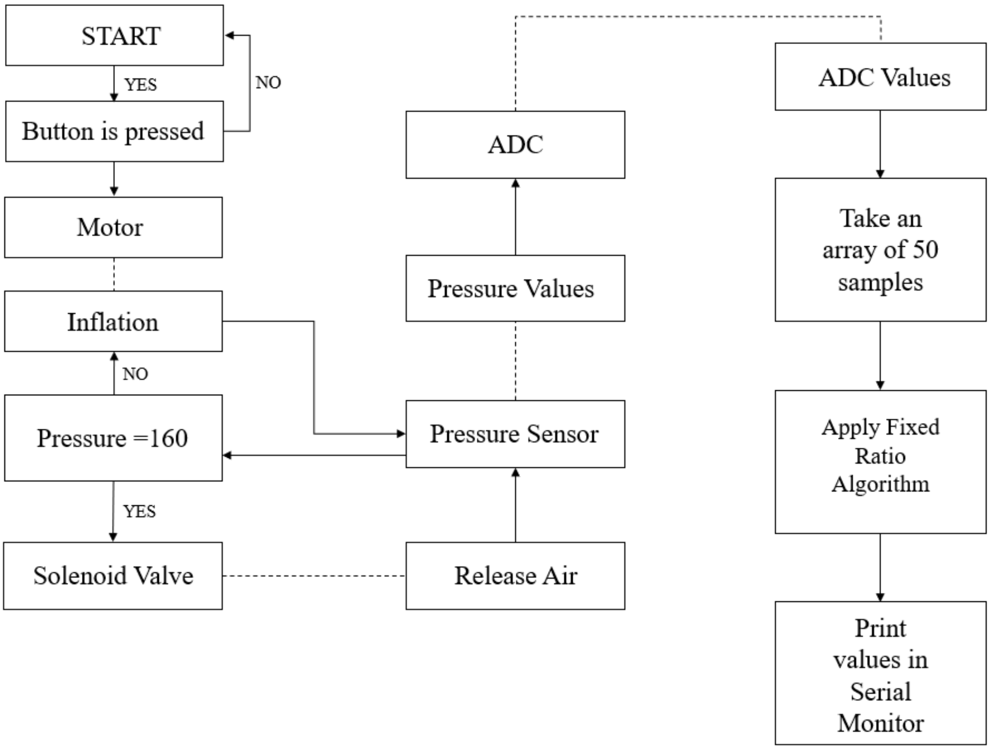
Valve, also known as the solenoid valve is used to deflate the air from the cuff. It also requires 12V DC supply. The valve is connected to the microcontroller through the solid-state relay.



Software:

The BPMD starts running immediately after the start button is pressed. The motor starts inflating the arm cuff step wise with the pressure sensor constantly checking if the pressure value inside the cuff has reached 160mmHg. Once the cuff pressure has reached 160mmHg we slowly start to release the air by opening the valve and we also start to measure the pressure from the sensor.

The pressure sensor values are filtered and given to the ADC of the microcontroller that samples the values and stores them in an array. We then apply the Fixed Ratio Algorithm to calculate the systolic and diastolic pressure.




```
/*Variable Declaration Start*/

int relayPin = 8;//Assign Pin 8 to the relay control/signal pin

float pmin=-15;

float pmax=15;

float vsupply=5;

float anvolt=0;

int i;

float maxvolt=0;

float volt=0;

float pressure=0;
```

```
float MAP=0;
float maxv=0;
float b;
float sys;
float dia;
float a;
int enA = 9;
int in1 = 13;
int in2 = 12;
/*Variable Declaration End*/

/*Setup Start*/
void setup(){
  Serial.begin(9600);
  pinMode(relayPin, OUTPUT);//Setting the Relay pin as an Output Pin
  if(digitalRead(3)==LOW){
    inflate();
  }
}
/*Setup End*/

/*Loop Start*/
void loop(){


}
/*Loop End*/

/*Motor Working Starts*/
void inflate(){
  //motor control
```

```
  pinMode(enA, OUTPUT);
  pinMode(in1, OUTPUT);
  pinMode(in2, OUTPUT);
  digitalWrite(in1, LOW);
  digitalWrite(in2, LOW);
  // Turn on motors
  digitalWrite(in1, LOW);
  digitalWrite(in2, HIGH);
  delay(60000);
  digitalWrite(in1, LOW);
  digitalWrite(in2, LOW);
  //presssure calculate
  a=calculate();
  Serial.print(a);
  if(a>=160){
    solenoid_relay_1();
    bp();
    solenoid_relay_2();
  }
  else{
    inflate();
  }
  if(digitalRead(4)==LOW){
    solenoid_relay_2();
  }
  solenoid_relay_2();
}
/*Motor Working Ends*/

/*Pressure Calculation During Cuff Inflation & Deflation*/
```

```
float calculate(){
  //ADC Conversion
  anvolt=analogRead(A0);
  volt=(anvolt*vsupply*1000)/(pow(2,10)-1);
  maxv=max(abs(volt-2.5),maxvolt);
  maxvolt=abs(maxv-2.5);
  //Pressure Calculation During Inflation
  pressure=((maxvolt)-(0.1*vsupply))/((0.8*vsupply)/(pmax-pmin))+pmin; //raw data into psi
  MAP=-1*(14.7-pressure*-1)*51.7-3.16/maxvolt; //psi into mmHg
  return MAP;
}
/*Pressure Calculation During Cuff Inflation & Deflation*/

/*BP Measurement*/
void bp(){
  for(i=0;i<50;i++){
    anvolt=analogRead(A0);
    volt=(anvolt*vsupply)/(pow(2,10)-1);
    maxv=max(abs(volt-2.5),maxvolt);
    maxvolt=abs(maxv-2.5);
    delay(250);
  }
  //raw data into psi
  pressure=((maxvolt)-.1*vsupply)/((.8*vsupply)/(pmax-pmin))+pmin;
  //psi into mmHg
  MAP=-1*(14.7-pressure*-1)*51.7-3.16/maxvolt;
  sys=MAP*1.1;
  dia=MAP*0.8;
  Serial.print(sys);
  Serial.print("/");
```

```
  Serial.print(dia);
}
/*BP Measurement*/

/*Valve Working Starts*/
void solenoid_relay_1(){
  //Turn the relay ON for 1 second
  digitalWrite(relayPin, HIGH);
  delay(1000);
  //Turn the relay OFF
  digitalWrite(relayPin,LOW);
  //Pressure Calculation
  b=calculate();
  //
  if((b<150)){
    bp();
  }
  else if(b>135){
    solenoid_relay_1();
  }
  else if(b<130){
    inflate();
  }
}
/*Valve Working Ends*/

/*Valve is opened*/
void solenoid_relay_2(){
  digitalWrite(relayPin, HIGH);
}
```

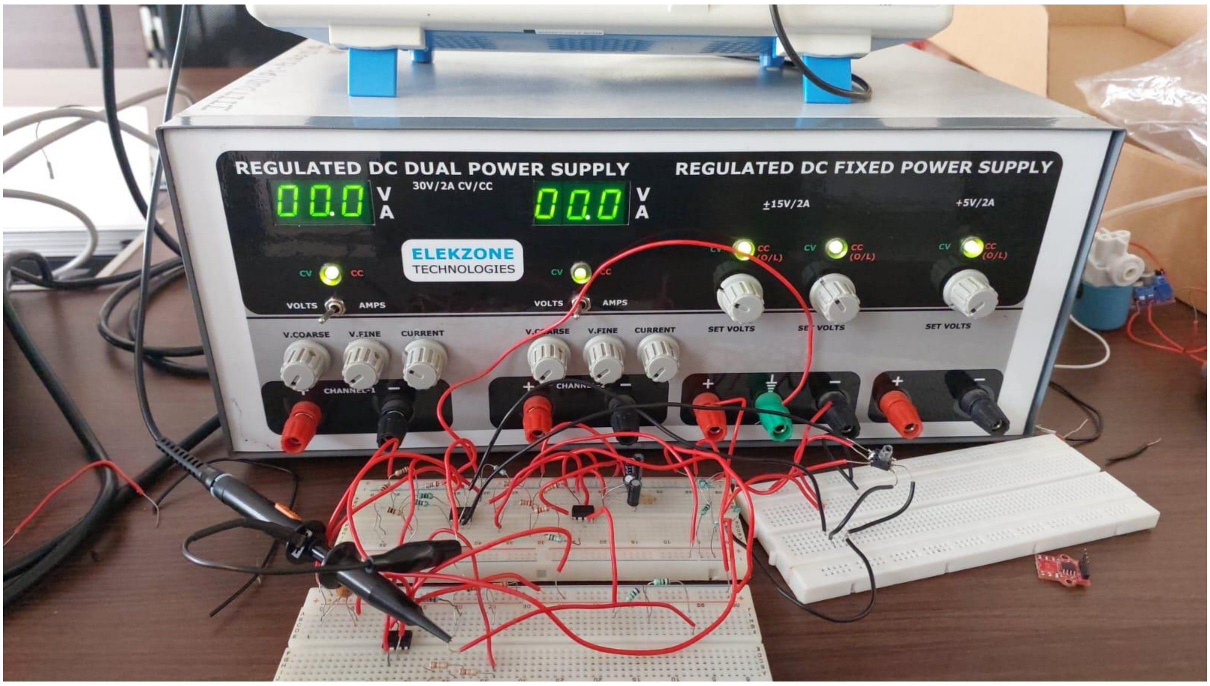
/*Valve is opened*/

/*Exit Program*/

```
void reset(){
   exit(0);
}
```

/*Exit Program*/

Photos:


REGULATED DC DUAL POWER SUPPLY
30V/2A CV/CC
REGULATED DC FIXED POWER SUPPLY
±15V/2A
+5V/2A
ELEKZONE
TECHNOLOGIES
VOLTS
AMPS
V.COARSE
V.FINE
CURRENT
SET VOLTS

135.52/98.56

Future:

- The BPMD can include multiple different algorithms to reduce the error.
- Also, the cuff inflation can be adjusted according to the user's preference.
- The error can be reduced by collecting more data from patients.
- With the use of a PCB the noise from the circuit can be significantly.
- The BPMD can be made portable by using batteries this can ensure usability.

References:

1) https://people.ece.cornell.edu/land/courses/ece4760/FinalProjects/s2005/ww56_ws62/Final%20Project%20Web/
2) https://www.instructables.com/Blood-Pressure-Monitor/

Literature Survey:

AUTOMATED BLOOD PRESSURE MEASURING SYSTEM						
TEAM MEMBERS: Anil Kumar, Eswar Naik, Raunit Pratik, Sithartha, R S Gokul Varun						
SERIAL NUMBER	**YEAR**	**NAME**	**DESCRIPTION**	**SUMMARY**	**ADVANTAGES**	**DISADVANTAGES**
1	2019	Arm Simulator For Blood Pressure Measurement	This thesis details the procedure to develop an arm simulator for a digital BPMD.	A detailed view of the hardware component connection is given. A T-connector is used to connect the cuff to the BP monitor and the pressure sensor.		
2	2019	Embedded Programmable Blood Pressure Monitoring System	This paper proposes a more efficient algorithm for BP measurement along with the design of a programmable BPMD.	A new algorithm using the slope method is used to find the upcoming value and estimate the sampled value. The amplifier is designed in such a way that the output value of the sensor is zero at zero input pressure. Since there is always an offset we need to compensate this offset.		
3	2019	Omron Gold Blood Pressure Monitor	The best premium product available in the Indian market.	The high morning average indicator alerts the user if systolic and diastolic measurements are out of normal range in the morning when there is a high risk for heart attack or stroke.	**1)** Morning BP alert system is a unique feature in this model. **2)** Has both Bluetooth connectivity and app connectivity. **3)** Can alert the user to irregular heartbeats. **4)** Can average 3 consecutive readings.	1) App connectivity is irregular 2) Medical data has to be shared with the company for enabling Bluetooth and app connectivity. 3) Error due to continuous measurement.
4	2018	Oscillometric blood pressure estimation algorithms	This article explains the formulas to explain three algorithms that are used to estimate blood pressure	The algorithms are as follows:- 1). derivative algorithm-:the derivate algorithm estimates diastolic BP and systolic BP at which the oscillogram has maximum slope and imum slope respectively. 2).fixed ratio algorithm- this algorithm estimates systolic pressure as the external pressure at which the falling portion of oscillogram is some ratio of its maximal value and diastolic pressure is estimated as the external pressure at which the rising portion of oscillogram is some ratio of its maximum value. 3). maximum amplitude algorithm- The maximum amplitude algorithm estimates mean BP (Pm) as the external pressure at which the oscillogram has maximum value (Pmax).		
5	2018	Design and Implementation of a blood pressure system	This project report gives us an overview of the designing process of the BPMD.	By studying the data gathered, an appropriate programming code can be written for determining the BP level. The signal data for every 40 ms. The controller will store the peak values and the pressure values accordingly. After the deflation is complete, the controller will analyze the stored peaks and determine the systolic and diastolic pressure.	The sampling time is appropriate enough to prevent data loss.	Because the controller is depending the voltage signal for BP measurement, the controller Peaks (in digitized value) v/sTimeline (ms) and Signal Peaks (in digitized value) v/s Timeline (ms) Signal Peaks (smoothened) might also capture the noise.
6	2018	Portable Digital Blood Pressure Monitor	This project from Cornell University aims to design a portable digital blood pressure monitor that can measure the user's blood pressure and heart rate through an inflatable arm cuff.	We learn the detailed method of finding systolic and diastolic pressure and heart rate. Also, the program flow and firmware execution of the blood pressure measuring device is given in detail. We determine the systolic pressure followed by the heart rate and the diastolic pressure is measured in the end.	The device uses separate power supply for the motor and the microcontroller thus increasing the life span of the device.	This device does not take repeated measurements.
7	2018	Blood Pressure Meter Design Using Microchip's Analog Devices and PIC24F Microcontrollers	This application note demonstrates the implementation of a digital BPMD.	This demo model uses a technique called Measurement While Inflation (MWI) reducing the overall measuring time thus effectively decreasing user discomfort. The measurement starts immediately after the cuff pressure slightly exceeds the arterial pressure. The sampling of the blood pressure signal starts immediately at pressure near the arterial pressure when light variations can be sensed by the sensors.	The MWI method is very efficient in reducing the time taken to measure blood pressure.	Simultaneous measurement of BP and deflation of the cuff can cause a pipelining error.
8	2017	Sources of inaccuracy in the measurement of adult patients' resting blood pressure in clinical settings	This study provides healthcare providers with knowledge of the factors that affect the measurement of BP and induce errors.	The study points out that errors in BP measurement can be induced by - acute meals ingestion, acute alcohol use, exposure or use of nicotine, bladder distension, paretic arm, white coat effect (BP changes due to the presence of a clinician), insufficient resting period, body position, legs crossed at knees, unsupported back, placement if arm lower than heart level, placement of cuff, fast cuff deflation. rate, reliance on single measurement		
9	2017	The role of the measurement uncertainty and error in the blood pressure measurement	This study aims to investigate the impact of measurement error and uncertainty in the misdiagnosis of hypertension.	It shows the measurement uncertainty, as part of the measurement error, impacts the diagnosis, causing misdiagnosis and affecting the patient treatment. Moreover, the closer the instrument indication is to the threshold of hypertension, the greater the incorrect diagnosis, due to the area covered by true value.		

10	2015	A model of an automatic blood pressure monitoring system and trigger for hospitals	This paper focuses on the development of a BPMD system that uses wireless connectivity to alert the doctor about the patient's BP.	Bluetooth connectivity is used to alert the doctor about the patient's BP if it crosses the safety level to provide immediate medical help.		
11	2015	Omron HEM 7124	This is the most cost-effective product currently in the Indian market.	This product uses Intellisense Technology to decrease the discomfort experienced by the user. The cuff inflation pressure is varied according to the user. The cuff inflation pressure need not be entered manually.	**1)** Pulse Measurement range - 40 beats to 180 beats **2)** Has cuff wrapping guide **3)** Can store the measurements in memory	**1)** Is more prone to errors while undertaking continuous measurements **2)** Small cuff size **3)** Cannot find the irregular heartbeat of a patient
12	2015	Comparison of the accuracy and errors of blood pressure measured by 2 types of non-mercury sphygmomanometers in an epidemiological survey	This research paper studies the comparison of the values of the oscillometric BPMD and the medical standard mercury sphygmomanometer in an epidemiological survey.	The error in the measurement of the diastolic pressure is more than the error while measuring the systolic pressure. The values also hugely vary depending on the age, positioning of the arm, placement of the cuff, and body fat percentage. Also, female patients were underestimated for diastolic pressure compared to their male counterparts.	It gives us the observation that based on a few changeable factors we can try reducing the errors.	This study is limited to the direct comparison between 2 products. And because only two models were used we cannot generalize the result.
13	2013	Design and Implementation of a Low - Cost Blood Pressure Measuring Device	This paper aims to design a low cost BPMD.	We get an idea of the software flow of the device. After the power switch is turned on, the system goes to the Start Mode and waits until the user presses the Start button. There is an Emergency mode that quickly deflates the cuff to ease the user in case of discomfort. The cuff is slowly deflated after reaching 160 mmHg and the pressure sensor starts working at this point. During this time, the systolic and diastolic pressure values are displayed. In case the Resume button is pressed then the whole process is performed again or else the functioning of the device stops.	The device design works in a precise manner following the program flow. It also takes into consideration the user experience.	This device cannot take multiple measurements which are usually required to reduce the error. Continuous measurement can give us a chance to correct errors in the previous measurements.
14	2013	Non-Invasive Blood Pressure Monitoring	This tutorial gives an overview of the basic functioning of the digital BPMD.	In this method, we lower cuff pressure at a controlled rate and as the pressure decreases, blood starts to flow through the artery. The increased blood flow causes the amplitude of the pressure pulses in the cuff to increase. The pressure pulses vary with the cuff pressure. The cuff pressure at which the pulse amplitude is the greatest is known as the Mean Arterial Pressure (MAP). The manner in which the pulse amplitudes vary is called a pulse envelope. The cuff is deflated in discrete steps, the typical step size is from 4mmHg to 10mmHg. Two measurement methods: the height method and the slope method are used.		
15	2012	Noninvasive blood pressure (NIBP) measurement by oscillometric principle	This research paper describes the development of a NIBP device based on oscillomentric principle.	We use a bandpass filter with cutoff frequencies of 0.3 Hz and 6 Hz to remove high-frequency signals, including the power line noise. The bandpass filter is constructed to achieve the required amplification. The filtered pressure oscillations have been used to indicate the point of systolic and diastolic pressure.		The demo device is not particularly suitable for multiple continuous measurements which can cause errors in the measurements.
16	2011	Analog Front End Design of Digital Blood Pressure Meter	This research paper describes the design of analog front end and proof of concept of a digital blood pressure monitor system using the same.	The cuff of the BPMD is controlled through the microcontroller using the Pulse Width Modulation (PWM) technique. The pressure sensor output is processed and then compared with the DC pressure of the cuff to obtain the exact blood pressure readings. The highest frequency we need to sample does not exceed 5 Hz. So according to the Sampling Theorem and taking into consideration the fluctuations, we should sample at a 50 Hz - 100 Hz frequency. Also, we should sample the cuff's DC pressure at an approximate rate of 250 Hz.	The sampling rate is efficient in measuring the BP values to a particular accuracy	The sampling rate is not absolute and has to changed based on the fluctuations introduced by the components used.
17	2011	Blood Pressure Monitor - Fundamentals & Design	This article demonstrates the implementation of a digital BPMD.	Each state machine is a task that has to be performed by the MCU. The system can perform several tasks, completing one at time and not running the next one until the previous one is complished in a FIFO (First In First Out) order. MED-BPM software is divided in three main parts—Initialization, communication with PC, and measurement execution.		