EE2301
HEARTBEAT MONITOR

Harishankar M
EE21BTECH11022

AIM
To design and implement a heartbeat monitor using a Photoplethysmogram (PPG) device

INTRODUCTION
Photoplethysmography (PPG) is a novel method used for monitoring of the heart functioning via uncomplicated and inexpensive optical measurement.It uses a light source and a photo detector to analyze the volumetric variations of the blood circulation .This method of monitoring the cardiac activity offers more flexibility,portability and convenience compared to tradition methods like ECG.

The heart activity is monitored by placing the PPG apparatus on certain body locations like finger tips,wrist,ankle etc.The Main part of the apparatus consists of a light source which in this case is a IR LED(emitting infrared light) and a photo detector like a photo transistor.
The IR LED sends out radiations which will get reflected and absorbed to the skin.Some part of the radiation will be absorbed by the tissues which will be almost constant with the time(corresponds to average blood volume in tissues).Some part of it will be absorbed by the Blood whose volume in the body part varies with the heart activity.This causes a variation in the reflected part as well which is captured by the photo transistor(The AC component) and this data is processed to monitor the heart activity.

COMPONENTS REQUIRED
TCRT5000
Resistors(1kΩ, 2kΩ, 100kΩ, 330kΩ, 10kΩ, 22kΩ)
Capacitors(1μF,0.47μF,220pF)
OP-AMPS(LM 358,LM 324),MOSFET(N7000)
Bread board,Connecting wires.

CIRCUIT DESIGN
The circuit consists of three stages :

1 The Photo detector

2 Filtering and Amplification

3 Processing

The Photo detector
The Photo detector circuit comes in direct contact with the skin and we use a TCRT5000 module for the same.The resistors connected to the photo transistor are selected for the proper biasing of the transistor.The resistors connected to the LED are selected to limit the current to the LED to prevent damage.The output from the Photo detector is very weak and and contains unwanted components like DC components and noises which need s to be filtered off by connecting it to the Filtering and amplification stage.The next subsystem to which the photo detector is connected needs to be of high input impedance in order to prevent loading and cause change in transistor current

The Filtering and Amplification stage
High Pass Filter(HPF)
This stage comprises of a single stage passive High pass filter which removes the low frequency components from the input signal like the DC noise.The subsystem has a high input impedance which suits the requirement of the previous stage.The cutoff frequency for the same is

$$f_{HPF} = \frac{1}{2\pi RC} = \frac{1}{2\pi * 1\mu F * 330k\Omega} \approx 0.483Hz$$

This stage is followed by a Voltage buffer using an OP-AMP in order to prevent the loading due to further stages.

Low Pass Filter(LPF)
This stage comprises of a single stage active low pass filter which removes the high frequency components from the input signal along with proving an amplification equal to 10X to the input signal.The cutoff frequency for the same is

$$f_{LPF} = \frac{1}{2\pi RC} = \frac{1}{2\pi * 0.47\mu F * 100k\Omega} \approx 3.38Hz$$

The output is connected to an amplifying circuit for further amplification of the signal.

Inverting Amplifier
This stage consists of an inverting amplifier with a unity gain .The amplifier is in inverting condition in order to counteract the inversion of the signal caused by the previous stage

The circuit diagram for the above stages is as follows.The op-amp used is LM 358 against LM741 as shown in diagram. (only one available in the design software)

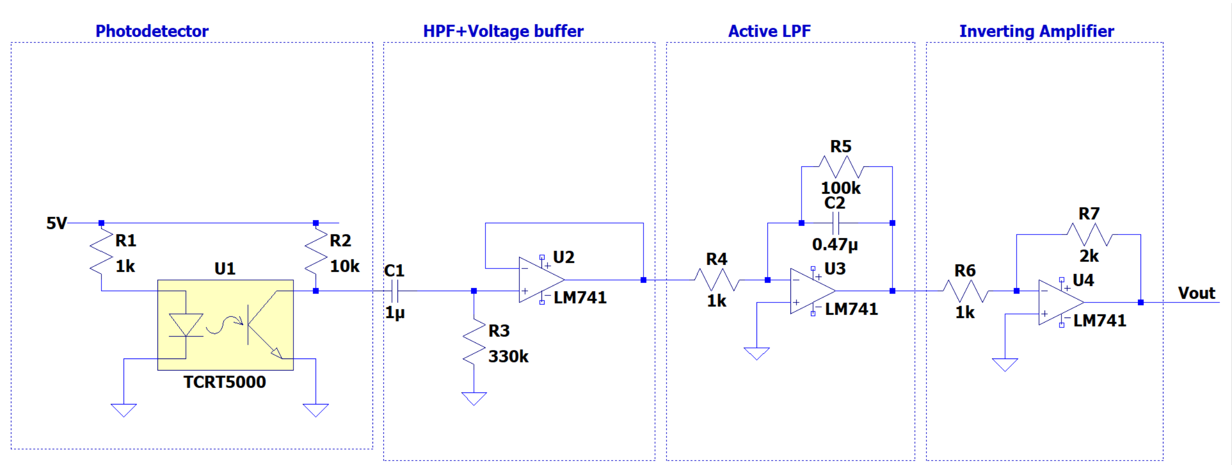


Figure 1: Circuit diagram-1

Processing
The processing consists of obtaining the required information from the PPG signal .The processing is done in Arduino.
Processing using Arduino
The output signal from the filtering and amplification(V_{out} is analog in nature and is given into the Arduino using the Analog pin(A_0).The signal is sampled and converted into digital format using the in

build Analog to Digital Converter.Afterwards we apply Fast Fourier Transform(FFT) to the obtained samples.We have used a sampling frequency of 8Hz and took samples in every 16s

Finding the Heart rate:The heart frequency is generally between 0.5Hz-2Hz.We first compute the FFT of the obtained samples.We then consider only the ones between frequency 0.5Hz-2Hz.The heart rate is approximated as the frequency with highest magnitude in the FFT.

Finding The Blood Pressure:The finding of the blood pressure is more complicated.In order to find the blood pressure, we need to find the Pulse Transit Time(PTT) which corresponds to taken by heart pulse to travel between two arterial sites.For finding of PTT, we generally require two PPG sensors which in our case is no available.Hence we took the fairly accurate approximation that the Systolic Period(time difference between the absolute minima and maxima of the pulse).Also we need to find the Heart rate in milliseconds(HR_{ms},given by

$$HR_{ms} = \frac{60000}{HR_{bpm}}$$

There is a strong relation between the Blood pressures with the HR and PTT.The relation can be linearized and the equation for SBP and DBP is given as

$$\begin{aligned} SBP &= 184.3 - 1.329 * HR_{bpm} + 0.0848 * T_d \\ DBP &= 55.96 - 0.02912 * HR_{bpm} + 0.02302 * T_d \\ T_d &= HR_{ms} - PTT \end{aligned}$$

The formula in the equations are obtained by linear regression of set of experimentally obtained values of Blood pressure,HR and PTT.The Arduino code is written so as to calculate these values and print them in the Serial Monitor(The Arduino code is attached in the drive link at the Bottom)

OUTCOMES
The circuital setup is as follows

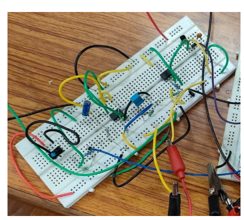
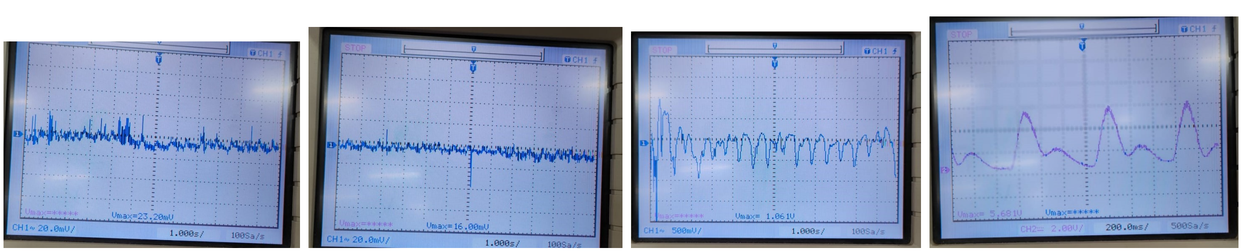


Figure 2: Circuit-1

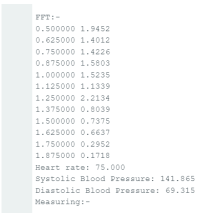
The signal output after each stage of the circuit is obtained as follows



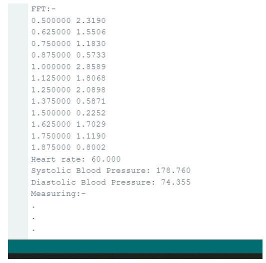
(a) TCRT5000-Output (b) HPF+Buffer-Output (c) Active LPF-Output (d) Inverting Amp -Output

Figure 3: DSO Readings

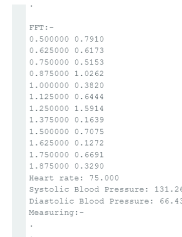
The outputs from the Arduino is as follows



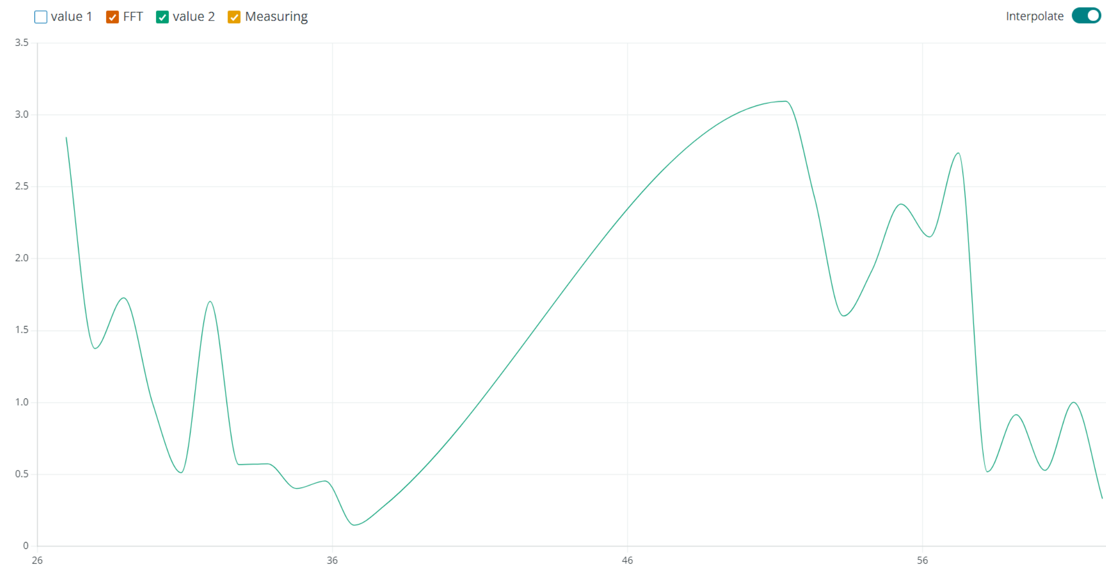
(a) Measurement-1



(b) Measurement-2



(c) Measurement-3



(d) Serial Plotter-Arduino

Figure 4: Arduino Output

Alternative:Usage of physically realized ADC instead of Arduino ADC.
The sampling and conversion of the Analog signal to a Digital signal can alternatively realized by building an ADC using OP-AMPS.This job was earlier done inside the Arduino using the in build ADC in the Arduino.The ADC we designed was a 3 bit ADC.Also a sampling circuit was also designed to sample the analog signal which is then supplied to the ADC.

The Sampling Circuit
The circuit used is a simple ample and hold circuit which consists of a MOSFET(N700) and a capacitor.The MOSFET is switched ON using a pulsing voltage causes the charging of the capacitor (sampling) and when the voltage is turned off causes the voltage to be stored in the capacitor (holding).Sampling is done before converting the analog signal to digital signal because the ADC would have some time delay for the conversion and the input signal need s to be constant in this region which is realized by sampling the analog signal.

The ADC
The ADC consists of a sequence of comparators which compares the input voltage with a reference voltage and give 'HIGH' or 'LOW' output which are the saturation voltages of the comparators .We connect the comparators in a parallel fashion and use an encoder to obtain the digital output.The reference voltages are given using a voltage divider network using resistors.
The circuit for the Sampling circuit along with the ADC is as follows.
The 7-output from the comparator is given to an 8 bit encoder(the last bit connected as ground).Since 8 bit encoders were not available,an Arduino was used to do the encoding (The Arduino code is attached

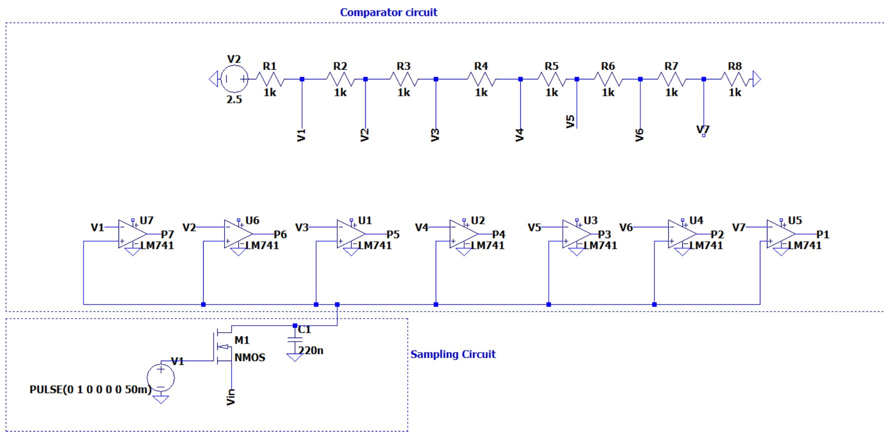


Figure 5: Circuit diagram-2

).The output from the encoder is in digital form which can be further processed(like applying FFT) so as to obtain the cardiac data. The circuital setup is as follows..The op-amp used is LM 324 against LM741 as shown in diagram. (only one available in the design software)

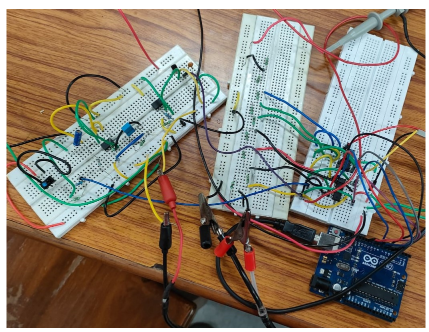
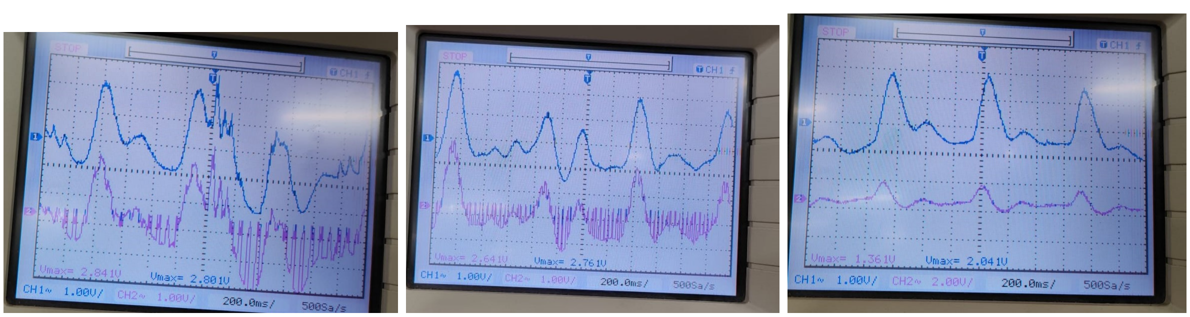


Figure 6: Circuit-2

The output from sampling circuit is as follows.



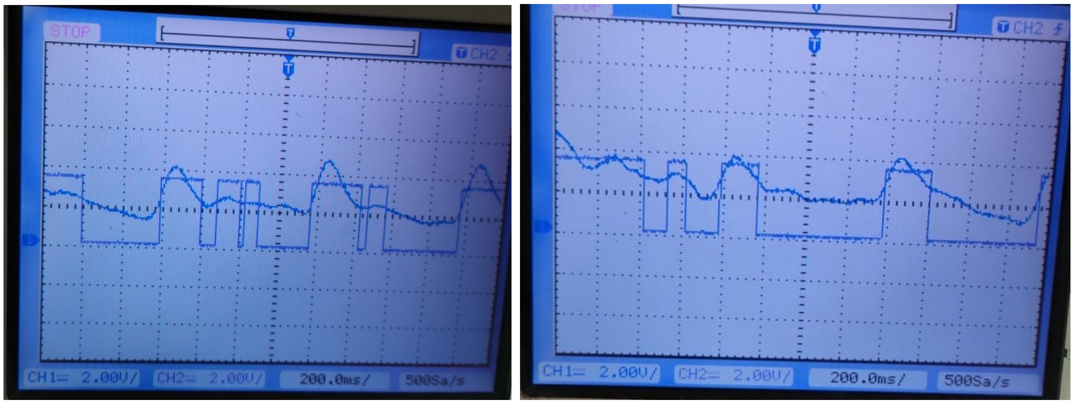
(a) Sampling Freq-15Hz

(b) Sampling Freq-30Hz

(c) Sampling Freq-500Hz

Figure 7: DSO reading-2

Digital output(DSO reading) as got from the comparators is as follows(The input signal is measured as reference in background)



(a) Digital output-1 (b) Digital output-2

Figure 8: Sampled output

The output from the Arduino was captured into an excel sheet(Also Attached) .

1	Data In (From Arduino Uno (COM6))										
2	Data coming from the current data source will appear below as it is received.										
3	Current Data										
4	TIME	CH1	CH2	CH3	CH4	CH5	CH6	CH7	CH8	CH9	CH10
5	15:15:42.51	0									
6	Historical Data										
7	TIME	CH1	CH2	CH3	CH4	CH5	CH6	CH7	CH8	CH9	CH10
8	15:15:42.45	0									
9	15:15:42.46	0									
10	15:15:42.46	100									
11	15:15:42.46	100									
12	15:15:42.47	TBL_HST[CH1]									
13	15:15:42.48	0									
14	15:15:42.48	111									
15	15:15:42.49	111									
16	15:15:42.49	0									
17	15:15:42.49	0									
18	15:15:42.50	111									
19	15:15:42.50	111									
20	15:15:42.51	0									

Sheet1 | Data In | Data Out | Settings | Manifest

(a) Digital output-1

Figure 9: Excel Sheet

CONCLUSION With the project, we were able to show that cardiac activity measurements could be made with reasonable accuracy using low power IR LED using and simple circuital elements.The processing was mainly done in Arduino .Better processing and accuracy could be employed to decrease the processing time using dedicated FFT hardware and DSP processors.It was also noted that the accuracy of the FFT also depends on the sampling time.Also more accuracy in Analog to Digital Conversion when done manually by adding more comparators and using a higher bit encoder.

REFERENCES
Websites

1 Measuring BP-https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6603632/

2 Measuring BP-https://ieeexplore.ieee.org/document/5754203

3 Sampling Circuit-https://www.electronicshub.org/sample-and-hold-circuit/

4 ADC:https-//www.electronics-tutorials.ws/combination/analogue-to-digital-converter.html

Arduino Code

1 Heart Monitor

2 Encoder

The demo video of the working along with the Excel sheet (encoder output) and the Arduino code is uploaded into the following drive folder.

- Google drive