HEART RATE MONITOR

IR - Pulse Plethysmograph

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• <u>Introduction</u>

1.1 Motivation

Blood pulse wave is one of the most important physiological parameters for the noninvasive diagnosis and monitoring of cardiovascular diseases. In many cases, such as during surgery as well as in Intensive Care Unit (ICU), there is a need to monitor the continuous blood pulse wave in real time. Blood pulse wave continuously monitored in real time by direct catheter insertion. However, catheter insertion always brings lots of risks of embolism, arrhythmia, heart attack, and certain percent of mortality. Therefore, noninvasive monitoring of blood pulse wave is preferred.

Continuous and noninvasive arterial blood pulse wave monitoring is desirable for patient monitoring, especially in ICUs. The existing methods to measure arterial blood pulse wave non-invasively include cuff sphygmomanometer, arterial tonometer, etc.

Cuff sphygmomanometer is the most standard manual technique used to monitor blood pulse wave for blood pressure measurement [1]. This method takes advantage of the Korotkoff sounds and presents two parameters, namely the systolic and diastolic pressure. However, with periodic cuff inflation and deflation, it cannot provide continuous beat-to-beat measurement of blood pressure. On the other hand, arterial tonometer is able to offer a continuous beat-to-beat pressure waveform but it is subject to motion artifact caused by the high sensitivity to sensor position and wrist movement [1].

A new method of continuous blood pressure monitoring was attempted by Penaz using photoelectric technique of detecting blood flow [2], using a transparent inflatable cuff controlled by a servo control system and placed on the human finger. This method is based on the idea that if an externally applied pressure in the cuff is equal to the arterial pressure at any instant, the arterial walls will be unloaded (zero transmural pressure) and the arteries will not change in size. In this condition, the blood volume will not change.

These above mentioned principles provide the motivation to design and implement a simple, low-cost, and stable continuous blood pulse wave monitoring system to facilitate the study of patients' clinical condition through observation of blood flow (related to changes in volume).

1.2 Objective and Scope

Based on the background and motivation discussed in Section 1.1, the project objective is to design and implement a noninvasive continuous blood pulse wave monitoring system that consists of transducer, data acquisition, and post processing. The signal obtained from a test subject (using a transducer) is passed through a signal conditioning circuit, digitized, and transferred to the computer. Signal post processing is performed to extract useful information about the test subject using appropriate algorithms in software.

The main goals of the project are:
1) To design and implement blood pulse wave monitoring hardware (employing transducer, operational amplifiers (op-amps) and other electronic components for signal conditioning, and an analog to digital converter, i.e., ADC for quantization).
2) To interface the digitized signal with the PC and to improve the quality of the digitized signal by performing digital filtering in software, if required.
3) To display the digitized signal on the computer and to perform post processing for extracting clinical information about the test subject.

• Related Work and Theory

2.1 Plethysmograph as a Volume Change Detection Transducer

The monitoring of blood flow using plethysmograph is the measurement of volume changes that result from the pulsations of blood occurring with each heartbeat. Such measurements are useful in the diagnosis of arterial obstructions as well as for pulse wave velocity measurements. Instruments measuring volume changes or providing outputs that can be related to them are called plethysmographs, and the measurement of these volume changes and the consequent phenomena is called plethysmography [3].

2.2 Infra-Red Pulse Plethysmograph [4]

In this project, an infra-red pulse plethysmograph (PPG) is used as a transducer. It uses an infra-red photoelectric sensor to detect and record changes in tissue blood volume from fingers, toes, ear, forehead, etc. Fig. 2(a) shows PPG model 1020 FC manufactured by UFI. Figure 2(a): PPG model 1020 FC manufactured by UFI.

2.2.1 Specifications

The model 1020 infra-red PPG has the following specifications:

Size 15 × 15 × 6.3 mm
Weight 28 g (approximately)
Excitation 20 mA at 6 to 9V DC nominal
Output 5 to 50 mV (typical finger application)

Output Impedance 1 KΩ nominal

Fig: 2(a) – PPG model 1020 FC manufactured by UFI.

2.2.2 Description

The UFI model 1020 PPG is a compact, flexible PPG transducer. It uses a matched semiconductor infra-red Emitter and Receiver pair to detect small changes in the reflectivity of the subject's skin (these changes are due to the inflow and outflow of blood associated with the beating of the heart). The use of the infra-red light spectrum helps minimize artifacts resulting from changes in ambient light.

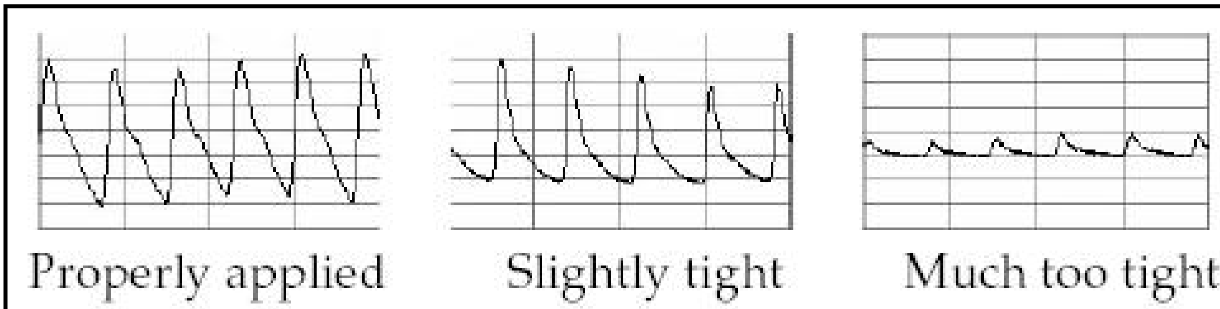

Fig: 2(b) – Various pulsatile signal qualities

• <u>Data Acquisition System</u>

3.1 Infra-Red Pulse Plethysmograph

Fig. 3(a) summarizes the entire data acquisition system (DAS) designed and implemented in this project.

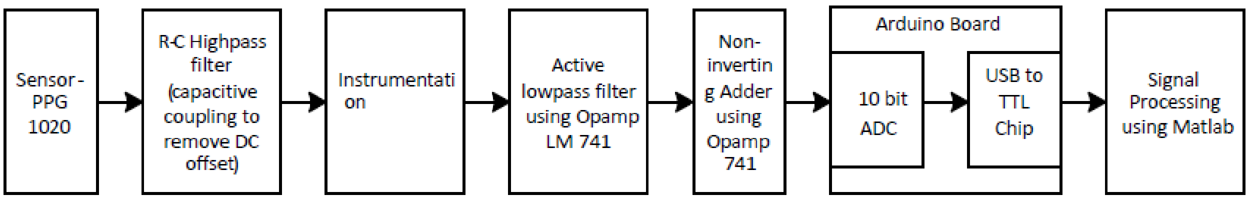

Fig: 3(a) – Block Diagram

3.2 Input Signal

Input signal in the analog signal conditioning circuitry is the pulsatile signal obtained from an infra-red pulse transducer; model 1020FC (Finger Clip). This transducer is used to record changes in pulsatile blood volume from fingers.
The amplitude of PPG signal obtained from the 1020FC PPG is 5 to 50 mV peak-to peak, typically for a resting subject. In order to make the PPG signal appropriate for further analysis, analog signal conditioning is performed.

3.3 Analog Signal Conditioning

3.3.1 Capacitive Coupling

The 1020FC produces 1 to 2 V DC offset component in addition to the PPG signal. Capacitive coupling is used to eliminate the average DC voltage component of the 1020FC output, in order to supply just the PPG signal to the amplifier. This approach involves connecting a capacitor between the 1020FC output and the amplifier input. A resistor is added between the amplifier input and ground to keep the signal ground referenced.

The capacitive coupling supplies a low frequency roll-off of 0.6 Hz (see equation 3.1). The average 1 to 2 V DC offset present on the output of the 1020FC is removed due to the high pass characteristic of the R-C circuit. The power supply of the PPG transducer is obtained using a voltage divider circuit.

$$fc = \frac{1}{2\pi RC} = 0.6Hz.$$

Impedance considerations

Care has to be taken to make sure that the resistor chosen is greater than 100 times the output impedance of the 1020FC transducer (which is 1KΩ nominal) in order to prevent attenuation of desired PPG signal due to loading effect.

3.3.2 Amplification

The signals obtained from transducers are usually too small to be used directly for post processing, so an amplifier is required to raise the signals to the appropriate level. Since the 1020FC supplies only one output signal, it is not necessary to use a differential amplifier to amplify the signal. A single-ended amplifier is usually sufficient. However, a differential amplifier can be used, since it is much more common, with the unused (inverting) input of the amplifier is connected to ground.

An Instrumentation Amplifier (IA) is used because it has high and balanced input impedance, high adjustable gain with low offset problem, and a high common mode rejection ratio (CMRR) which does not depend on matching of the resistors. The very high input impedance of the IA minimizes input signal loading effects from the finite source impedances. The gain of IA is easy to adjust by selecting appropriate external resistors Rf, Rg (see equation 3.2 below).

As the output signal from 1020FC is about 5 to 50 mV peak-to-peak, the amplifier circuit is designed to give gain of approximately 100. This output is suitable and sufficient for further analysis. Based on the gain equation of the IA, the resistors values for obtaining a gain of 100 can be calculated as follows

$$\boldsymbol{Gain = \frac{2Rf}{Rg} + 1}$$

3.3.3 Filtering

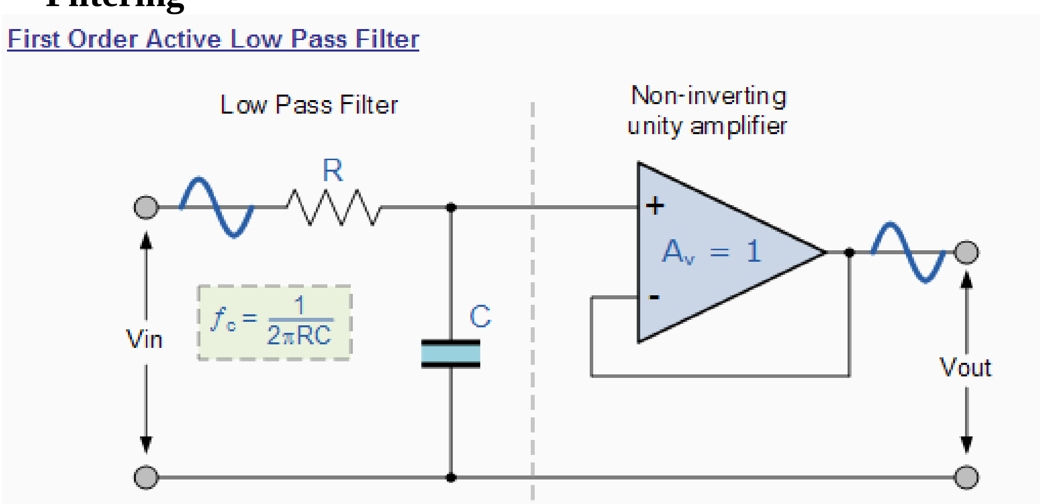

Fig: 3(b) Low Pass Filter

In this project, the bandwidth of the PPG signal is from 0.6 to 10 Hz. For low frequency filtering, this corresponds to a fairly high respiration rate of 36 breaths/minute, and for the high frequency filtering, the maximum heart rate might be 240 beats/minute, which corresponds to 4 Hz. So, filtering the PPG amplified output signal with a low-pass filter that rolls off at 10 Hz is more than sufficient. A high-pass filter that rolls-off at 0.6 Hz has been designed in the capacitive coupling for DC offset removal, using a high-pass RC filter as described in part 3.3.1. An opamp is used to design an active low-pass filter that rolls off at 10 Hz. The corresponding circuit is shown in Fig. 3(b).

3.3.4 Level Shifter using Non-Inverting Adder

In this DAS, the ADC used has a reference voltage range 0-5V DC. Hence, to shift the dual polarity filtered and amplified PPG signal to the positive domain, a non-inverting adder is designed using an opamp. Fig. 3(c) shows the circuit of the non-inverting adder wherein Vout = V1+V2. R is chosen as 1KΩ. V1 is the amplified and filtered PPG signal and V2 is set to be an appropriate fixed DC voltage using a voltage divider circuit.

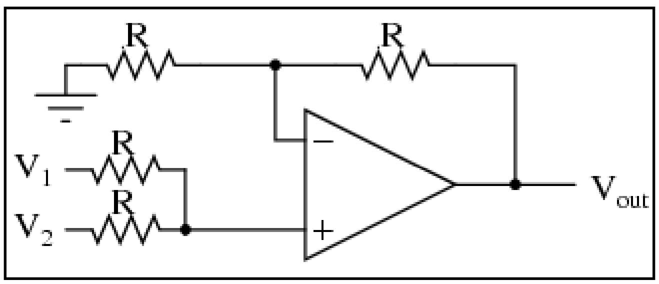

Fig: 3(c) – Non-Inverting Adder Circuit Diagram

3.4 Signal Acquisition and Post-Processing in MATLAB

MATLAB is used as a tool for building the interface between the ADC and the computer, and to control the access to the (virtual) COM port. The data read from COM port is further processed and analyzed to get the clinical data of the test-subject. The acquired samples of the PPG signal are filtered if required. Fig. 3(d) shows an example of the acquired signal.

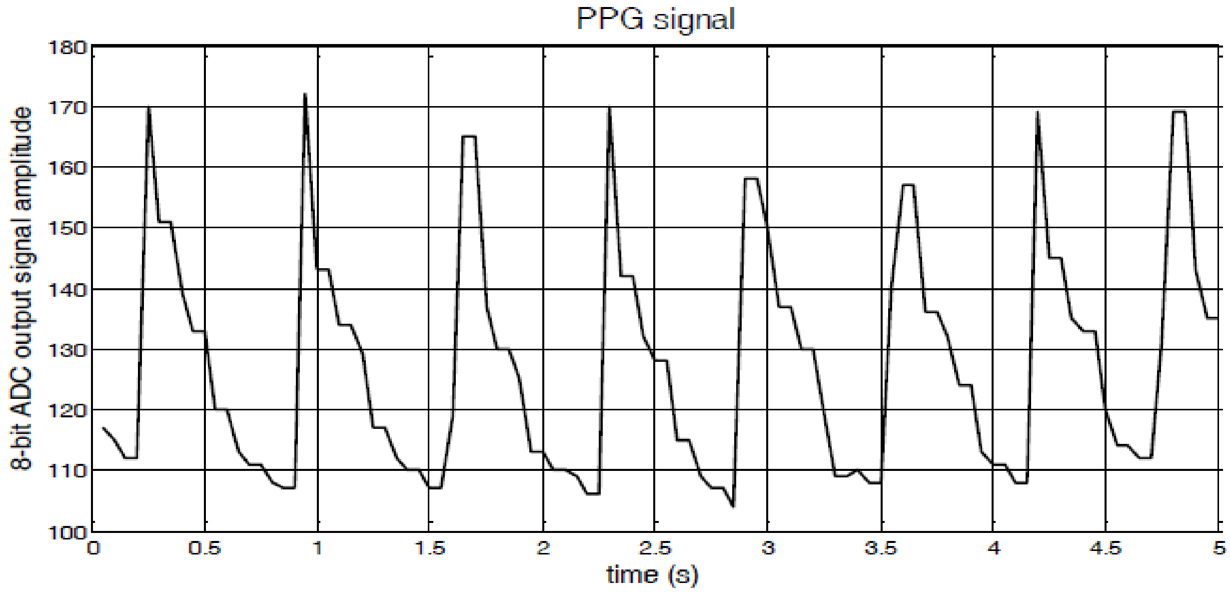

Fig: 3(d) Acquired PPG signal

- **<u>Experimental Setup</u>**

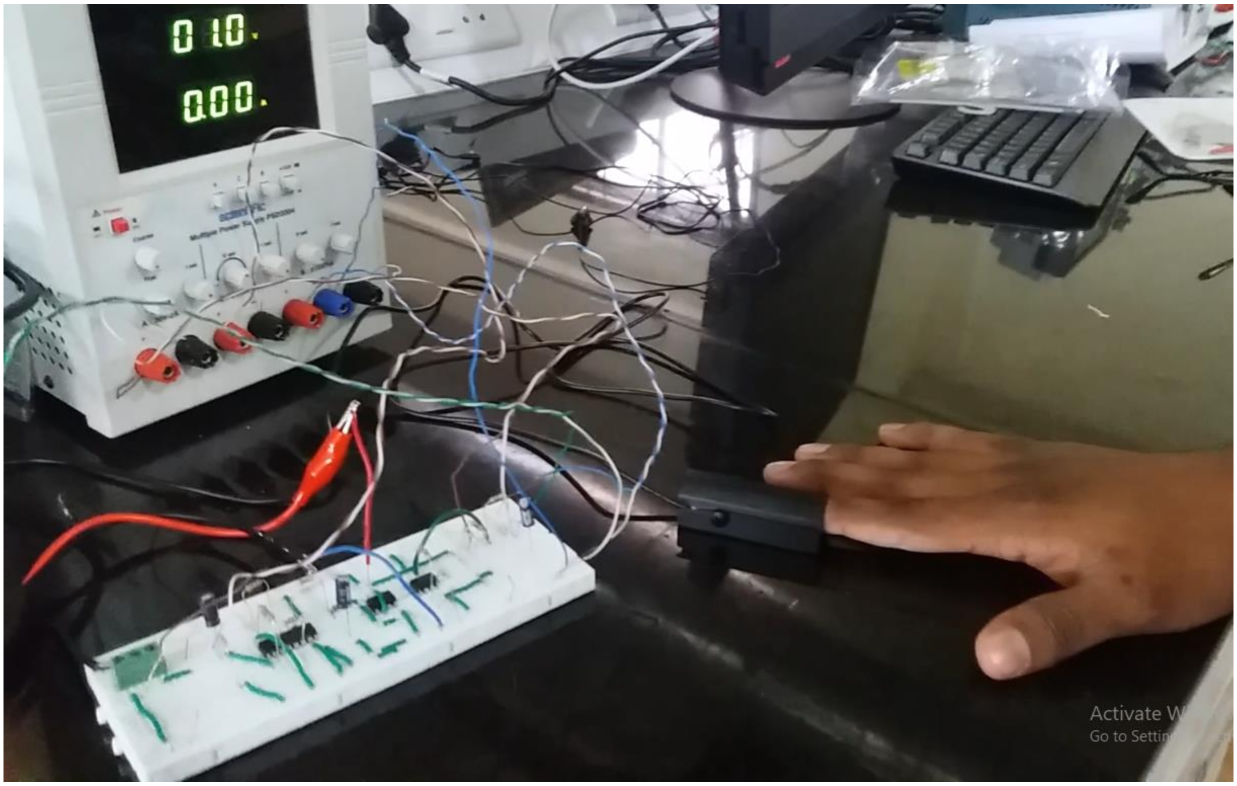
Fig: 4(a) Setup of PPG Data Acquisition System

Figure 4(a) shows the snapshot of the setup of the plethysmograph data acquisition system and the different sections in it.

The circuit comprises of the following main parts:

- Finger-clip transducer.
- Circuit assembled on breadboard - comprising of two operational amplifier, one instrumentation amplifier and one ADC ICs.
- Oscilloscope – to check and analyze waveforms at different stages in the circuit.
- Power supply – to provide dual 15V and single 5V supply.
- Computer – to acquire data and process it.

• Observations

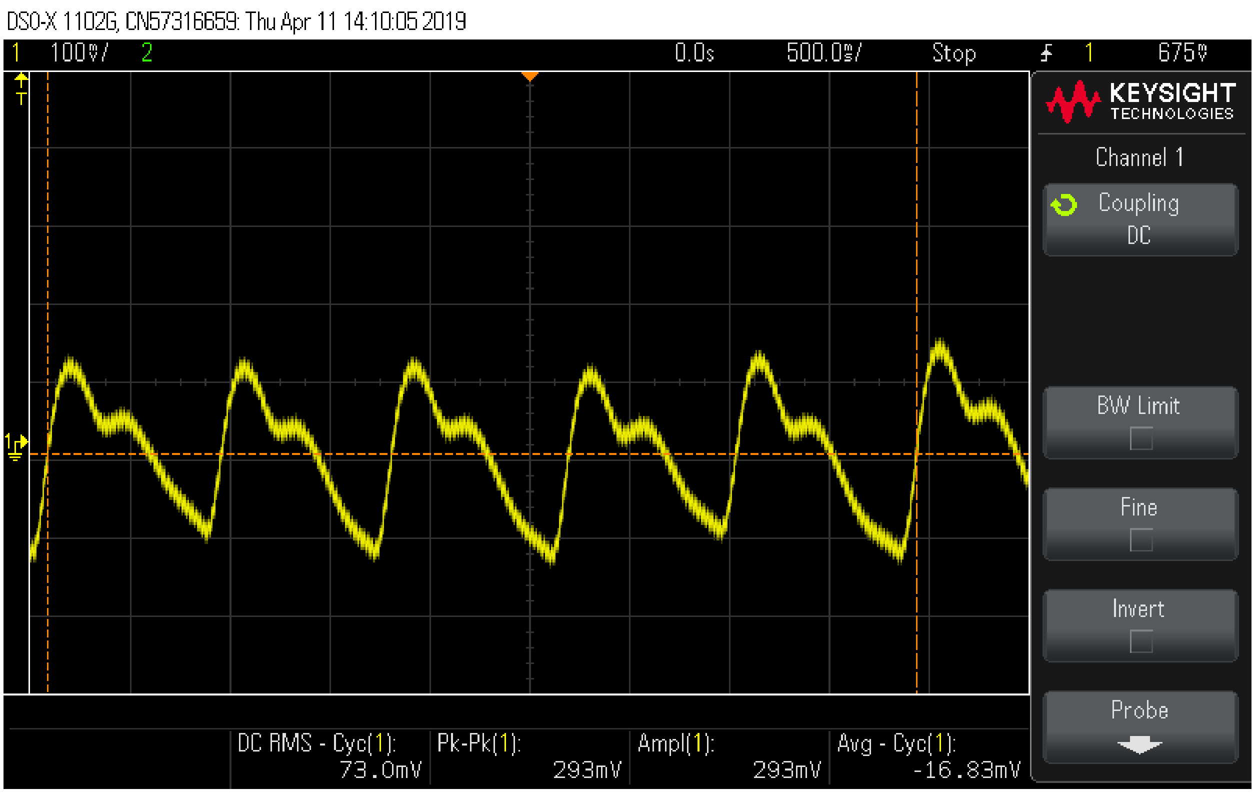

Fig: 5(a) Output of the setup on the Oscilloscope.

• Components

1. RC - High Pass Filter

   R = 220 kΩ;

   C = 1µF;

   f_c = 0.7234 Hz;

2. Instrumentation Amplifier

   R_f = 5.6 kΩ;
   R_g = 100 Ω;
   Gain = 112;

3. RC - Low Pass Filter

   R = 1.6 kΩ;
   C = 10 µF;
   f_c = 9.9472 Hz;

4. Non-Inverting Adder

   R = 1 kΩ;

- **User - Interface**

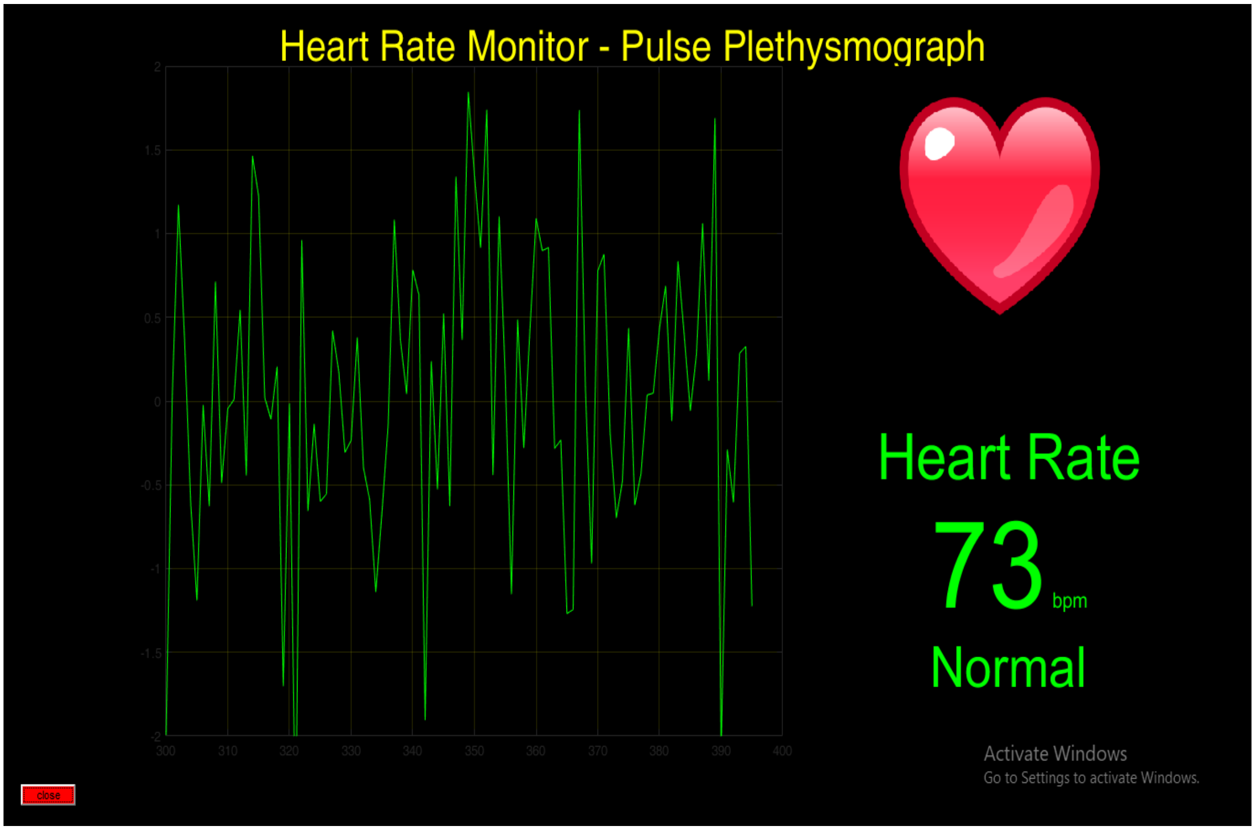

Fig: 7(a) – User – Interface in MATLAB

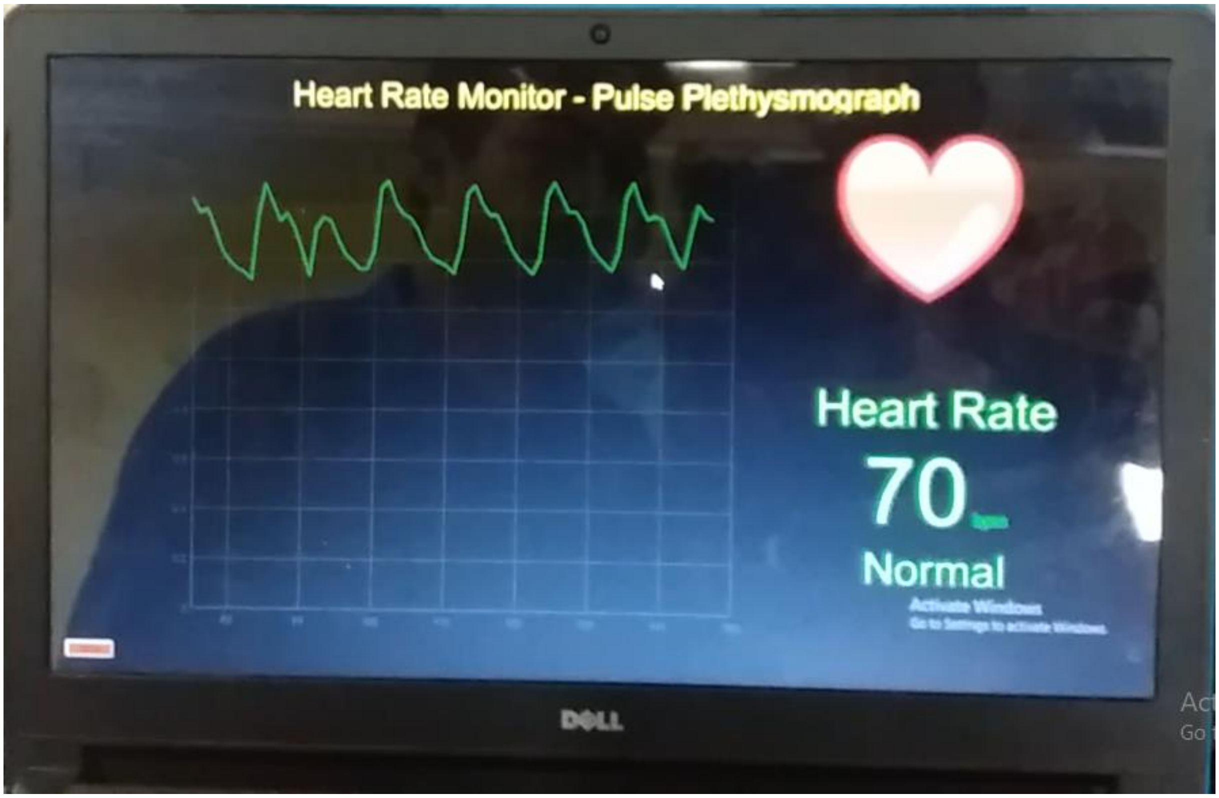

Fig: 7(b) Output on the screen when tested on a user.

- ## <u>MATLAB CODE</u>

```
clear all
%% Input Parameters
T = 100;
R = 1;
passo = 1;
t=1;
x=0;
% signal = randn(4,1000);  % When testing a random signal
h2 = 0;
a = arduino('COM10', 'uno');    % When taking the input from Arduino.
tic

%% Creating a new display
newFig = figure;
set(newFig,'name','Pulse Plethysmograph','numbertitle','off','color',
'k','menubar','none','toolbar','none') ;
suptitle({'\fontsize{30} \color{Yellow}Heart Rate Monitor - Pulse
Plethysmograph'});

%% Display image of heart
```

```
subP1 = subplot(2,3,3);
img = imread('normal_heart_rate.png');
imshow(img);

%% Creating a stop pushbutton
% toggle button to stop the simulation
stop = uicontrol('style','toggle','string','close','background','r');
set(stop,'style','pushbutton','string','close','callback','close(gcf)'
);

%% Reading the sensor input and plotting the plethysmogram
for j = 1:10
    for i = 1:100
        if get(stop,'value') == 1
            break;
        end

        b = readVoltage(a,'A1');
%         b = signal(j,i);
        x = [x,b];
        pause(0.01);
        subplot(2,3,[1 2 4 5]);
        plot(x,'g');
        ax = gca;
        set(gca,'Color','black')
        ax.GridColor = 'y';
        ylim([0,4])

        % pay attention to this command %
        axis([T*fix(t/T),T+T*fix(t/T),-2,2]);
        grid
        t=t+passo;
%         pause(0.01);
        drawnow;
    end

%% Computing Heart Rate and displaying img and text
    pause(0.001)
    [pks, locs] = findpeaks(x);
    Heart_Rate = uint8(length(pks)*60/toc);

    if Heart_Rate < 60
        subP1 = subplot(2,3,3);
        clear img
        img = imread('low_heart_rate.png');
        imshow(img);
```

```
        annote('\fontsize{40} Low',Heart_Rate);
    elseif Heart_Rate > 100
        subP1 = subplot(2,3,3);
        clear img
        img = imread('high_heart_rate.png');
        imshow(img);
        annote('\fontsize{40} High',Heart_Rate);
    else
        subP1 = subplot(2,3,3);
        clear img
        img = imread('normal_heart_rate.png');
        imshow(img);
        annote('\fontsize{40} Normal',Heart_Rate);
    end

end

comment_box(Heart_Rate);

function annote(string,Heart_Rate)
    annotation('textbox',[0.65 0.10 0.30 0.40],'String',...
    {'\fontsize{45} Heart Rate',...
    [' \fontsize{85}' num2str(Heart_Rate),...
    '\fontsize{15} bpm'],...
    string},...
    'FontSize',16,...
    'FontName','Arial',...
    'HorizontalAlignment','Center',...
    'LineStyle','-',...
    'EdgeColor',[0 0 0],...
    'LineWidth',2,...
    'BackgroundColor',[0 0 0],...
    'Color',[0 1 0]);
end

function comment_box(Heart_Rate)
    if Heart_Rate < 60
        waitbar(0.25,'Your Heart Rate is Low','Name','Heart Rate
Monitor');
    elseif Heart_Rate < 40
        waitbar(0.05,'Your Heart Rate is Too Low','Name','Heart Rate
Monitor');
    elseif Heart_Rate > 100
        waitbar(0.75,'Your Heart Rate is High','Name','Heart Rate
Monitor');
    elseif Heart_Rate > 130
```

```
        waitbar(0.95,'Your Heart Rate is Too High','Name','Heart Rate
Monitor');
    else
        waitbar(0.5,'Your Heart Rate is Normal','Name','Heart Rate
Monitor');
    end
end
```

- **References**

[1] Webster, J.G., Medical Instrumentation: Application and Design, 3rd edition. New York: Wiley, 1998.
[2] Penaz, J., Photoelectric Measurement of Blood Pressure, Volume and Flow in the Finger. In.: Proceedings of 10th International conference on medical and biological Engineering. Dresden, 1973.
[3] Cromwell, L., Weibell, F.J., Pfeiffer, E.A., Biomedical instrumentation and measurements, 2nd edition. Prentice-Hall, 1980.
[4] UFI, 1020 Infra-red Pulse Plethysmograph by UFI.
Available: http://www.ufiservingscience.com/
[5] Manufacturer datasheets of:
i) IC 741
ii) IC AD 625
iii) IC AD 0820
[6] https://www.arduino.cc/en/Main/ArduinoBoardUno

Click here for the Demonstration Video and Images Captured.