Optical measurement: Opto-physiological monitoring

Please note: This instruction provides an outline of experimental study of non-invasive opto-physiological monitoring and the learning outcomes that a typical student might reasonably be expected to achieve and demonstrate if full advantage is taken of the learning opportunities that are provided. More detailed information is available on the LEARN http://learn.lboro.ac.uk/.

1. Background

Loughborough University's Opto-physiological monitoring (OPM) as the evolution of conventional photoplethysmography (PPG) can been applied in present smartphone or similar gauges for human critical parameter monitoring. Together LU optoelectronic patch sensor system (namely Carelight), real time and continuous monitoring for heart and respiration rate, oxygen saturation becomes possible and durable.

2. Aims

- To understand the principles of Opto-physiological monitoring and associated monitoring skills through the measurement setting-up.
- To process PPG signals then display these critical physiological parameters with proper algorithms.

3. Intended Learning Outcomes

On completion of this session students should be able to:

1) Knowledge and Understanding

- understand the fundamentals of opto-physiological monitoring in particular photoplethysmographic (PPG) measurement and its applications.

2) Electronic systems

- explain the physical factors, i.e. walking, running etc. which affect measurements and PPG signals within real environments

- manipulate measurement and signal processing

3) Subject-specific skills

- understand the properties of commonly used optoelectronic sensor, measurement system and software.

- compare the properties of commonly used optical sensors in clinical settings, and smart devices.

4) Practical

- select an optoelectronic patch sensor (carelight) for a given application, i.e. Heart rate measurement.

- propose an engineering solution together with the selection of optoelectronic sensor and associated signal processing methods for biomedical monitoring

5) Key/transferable skills

- work effectively as part of a group to produce presentable results.

- evaluate current photonics-based health monitoring in electronic engineering applications

4. Teaching, learning and assessment strategies to enable outcomes to be achieved and demonstrated:

Knowledge and understanding of areas 1) are acquired through lectures, tutorials. The practically oriented knowledge of areas 2) – 5) is acquired in practical classes, both experimental and computing, and associated lectures.

Areas 1) – 2) are assessed by examinations and coursework. Areas 3) – 5) are mainly assessed by coursework supplemented by written and viva voce examinations.

Optical Measurement 1:

Opto-physiological Monitoring Setting-up and Signal processing

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1. Overview of Opto-physiological Measurement System

The Opto-physiological Measurement System, as illustrated below in ***Figure 1.***, captures Opto-physiological (PPG) Signals from the Optoelectronic Patch Sensor (namely Carelight Sensor) and motion status from a 3-axis accelerometer (ADXL337, Analog Devices Co., Palo Alto, MA, USA) during experimental measurements. All data sets from the sensor are collected by the means of the 4-channel Electronic Board (namely DISCO4) and the simulation software of Carelight Sensor is performed by LabVIEW GUI were PPG signals from the OEPS and signals from the accelerometer are recorded as well.

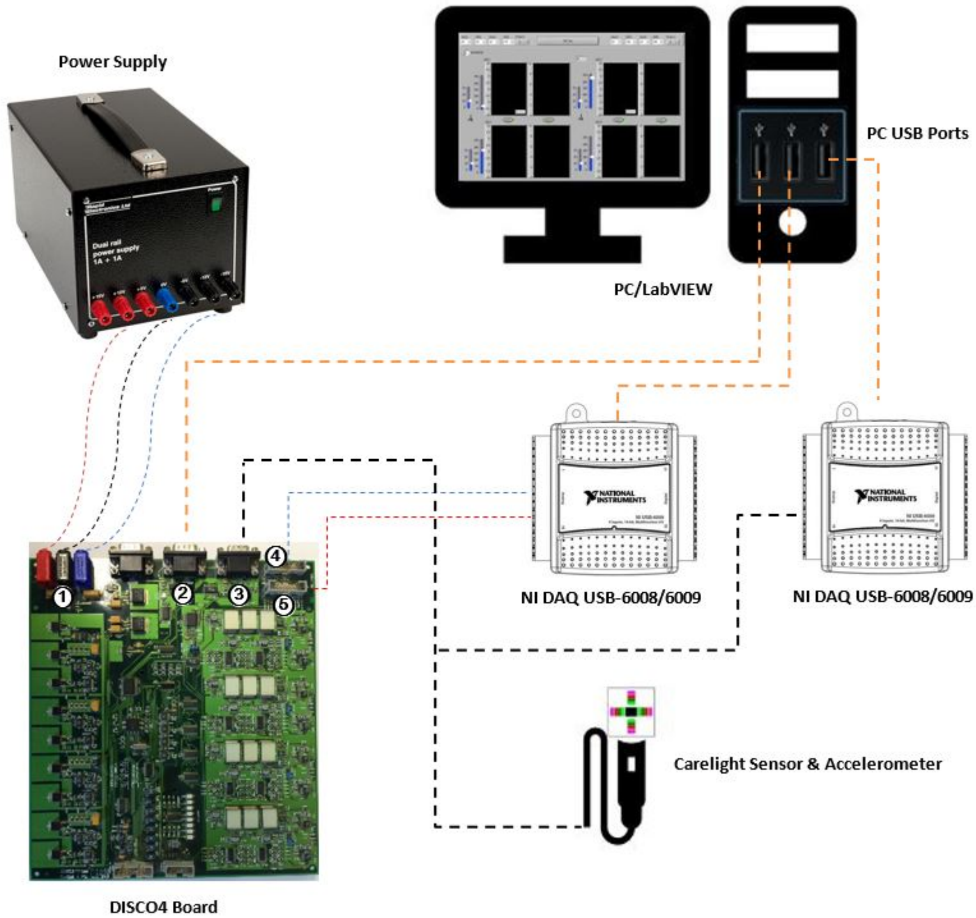


Figure 1. *Opto-physiological Measurement System Set-up*

The Opto-physiological Measurement System consists of:

- the Opto-Electronic Patch Sensor (OEPS) - Carelight Sensor and 3-axis Accelerometer
- an Electronics Board (DISCO4, Dialog Devices Ltd., Reading, Berkshire, UK)
- two Multifunction Data Acquisition USB Devices (DAQ, USB-6009, National Instruments Co., Novato, CA, USA)
- a power supply device (Dual Rail power supply, Rapid Electronics Ltd, Colchester, Essex, UK)
- a control and measurement software performed by LabVIEW GUI (National Instruments Co., USA)

Opto-Electronic Patch Sensor (OEPS) - Carelight Sensor

Loughborough University's Carelight is a wearable Opto-Electronic Patch Sensor (OEPS) that offers continuous monitoring of vital signs including Heart Rate, Respiration Rate, Heart Rate Variability, Blood Pressure, Temperature and Oxygenation levels.

The OEPS consists of Light-emitting diodes (LED's) as multi-wavelength illumination sources (LEDs of green 525 nm, orange 595 nm, red 650 nm and IR 870 nm (JMSienna Co., Ltd., Palo Alto, CA, USA) that convert electrical into light energy, a low-profile PiN photodiode (BPW34SR18R, Osram, GmbH) as a photodetector that converts electrons as light energy into an electrical current to detect any motion from the body. The Carelight sensor operates in reflectance mode (LED's and photodetector are placed side-by-side where the later collects the light reflected from various path length underneath the skin composites).

2 Electronics Board - DISCO4

The **DISCO4 Board** implements a four-wavelength opto-physiological measurement system that provides all the necessary analogue signal processing to perform multi-channel Photoplethysmography (PPG).

3 Multifunction Data Acquisition USB Devices

The two **DAQ USB Devices** (USB 6008/6009) provide basic DAQ functionality for the portable measurements and the Analogue-to Digital Conversion (ADC) for the captured PPG signals and the Accelerometer respectively.

4 Power Supply Device

The **Power Supply Device** is an electronic external device that converts the 220 voltage to the required voltage (15 V) and current type DC that is suitable for the operation of the DISCOA Board.

5 Control & Measurement Software

The Control and Measurement software is a customised development tool used through the LabVIEW GUI (National Instruments Co., USA). It depicts both filtered and raw waveforms obtained from the Carelight Sensor and it also provides the ability to the user to adjust the LED intensity and gain of the Carelight Sensor.

Hardware Set-up

System Connectors and Connections

The various connectors on the **DISCO4 Board**, along with their function and termination are described below, as earlier depicted on ***Figure 1.:***

① **Power Supply Connectors:** There are three power-supply connectors, VDD, -VDD and GND, standard banana plugs, which are colour coded (red = VDD, blue = -VDD, black = GND). The electronic board can be supplied with ±15V(nominal) when connected to the **Power Supply Device** mentioned above.

② **RS232 Master Serial Port Connector:** The MASTER connector is used to connect the Electronic Board to a **PC**. With a Serial-to-USB adapter cable it can be connected directly to a **PC USB Port**.

③ **Probe Connector:** The circuit uses a single 9-pin D-type female connector to connect to the **Carelight Sensor** for the PPG signals capture. The Accelerometer, on the other hand, is connected to a **Data Acquisition USB Device** which is in turn connected to a **PC USB Port** through a USB cable.

④ **Processed Outputs:** A single 16-way 0.1-inch pitch IDC connector is used as the output for all amplified and filtered output channels. These outputs are the main analogue outputs of the entire system and are taken from the very end of the analogue signal-processing chain. The outputs are connected to a **Data Acquisition USB Device,** for Analogue-to Digital Conversion (ADC), which is in turn connected to a **PC USB Port** through a USB cable.

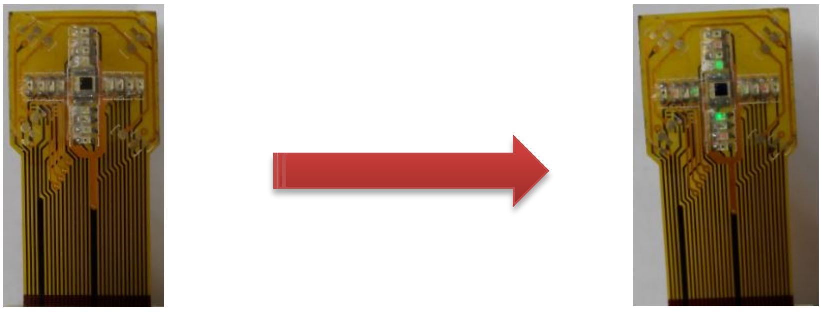
⑤ **Raw Outputs:** A single 16-way 0.1-inch pitch IDC connector is used as the output for the unprocessed output channels. The raw output signals are the various channels after de-multiplexing but before any analogue signal-processing (amplification and gain) have been applied. This connector is provided so that external analogue signal-processing could be used if required. The outputs are connected to the same **Data Acquisition USB Device** as in ④, for Analogue-to Digital Conversion (ADC), which is in turn connected to a **PC USB Port** through a USB cable.

1- Hardware Setup Steps

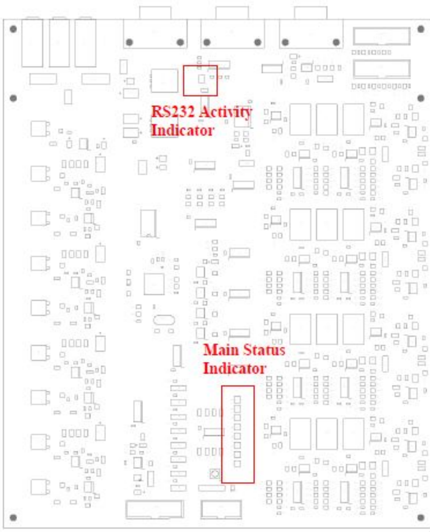
1. **Ensure** that the Opto-physiological Measurement System Connections are as Illustrated earlier in ***Figure 1.*** and as described above.
2. **Turn on** the power switch positioned on the front panel of the **Power Supply Device**:

3. **Ensure** that the LED’s on the sensor are dimly lighted as soon as you switch on the Power Supply Device:

*LED’s **before** turning on the switch* *LED’s **after** turning on the switch*



4. **Confirm**, when power is first applied, that one of the 8 LED indicators, positioned in a row and form the main board status indicator, is Illuminated. The LED positioned near the RS232 connectors illuminates when RS232 communications are active:



3. **Software Setup**

Two separate LabVIEW Virtual Instrument (.vi) files are used and already built up (namely ***DISCO4_A.vi*** and ***DISCO4_B.vi***) for the Opto-physiological Measurement System. These files usually can be found on the desktop of the running and connected PC.

Each of the two .vi files is configured to acquire and record data from each of the two different Data Acquisition USB devices correspondingly. The data recorded depends on what is connected to the DAQ inputs.

- ***DISCO4_A.vi*** is configured to acquire data from the DAQ USB device that is connected to the **DISCO4 Board** recording the PPG data (processed and raw signals) from the Carelight Sensor (as described above).
- ***DISCO4_B.vi***, on the other hand, is configured to acquire data from the other DAQ USB device that is connected to the Accelerometer.

The Read and Display Front Panel of the ***DISCO4_A.vi*** is illustrated in ***Figure 2.*** as follows:

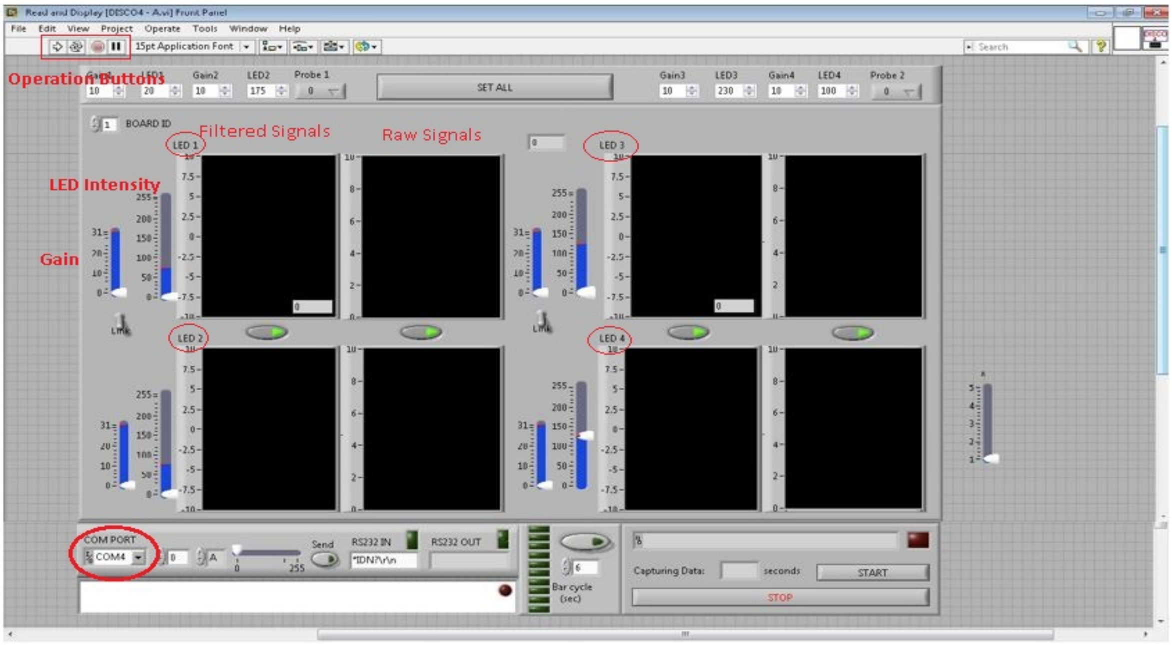


Figure 2. *Front Panel of DISCO4_A.vi*

<u>Note:</u> For ***DISCO4_B.vi*** you can choose any of the DAQ input channels (4 raw, 4 filtered data inputs) to connect the accelerometer to represent the X, Y and Z axis of the accelerometer. For example, if you connect the X, Y and Z axis to the raw input channels in the DAQ, you will see the accelerometer data in the raw windows in LabVIEW.

1. **Open** the two .vi files (***DISCO4_A.vi*** for recording PPG data and ***DISCO4_B.vi*** for recording accelerometer data), by double clicking on them, on two different screens.

Before running the two VI's:

- **Choose** the right **COM port** for ***DISCO4_A.vi*** in the Front Panel*, (**Figure 2.**)* that corresponds to the USB port through which the PC is connected to the DISCO4 Board. (make sure a different COM port is chosen for ***DISCO4_B.vi***)
- **Initialize** the **DAQ Assistant**, for each of the VI's, as follows:

Go to the Window Tab in header bar > Show Block Diagram and as soon as the window appears then double click on the DAQ Assistant icon > select and remove the previous voltage channels > add new supported physical channels on the DAQ Device that corresponds to each of the VI's, press OK *(**Figure 3.**)*. At this point you can also change the Sampling Frequency (128, 256, 500…).

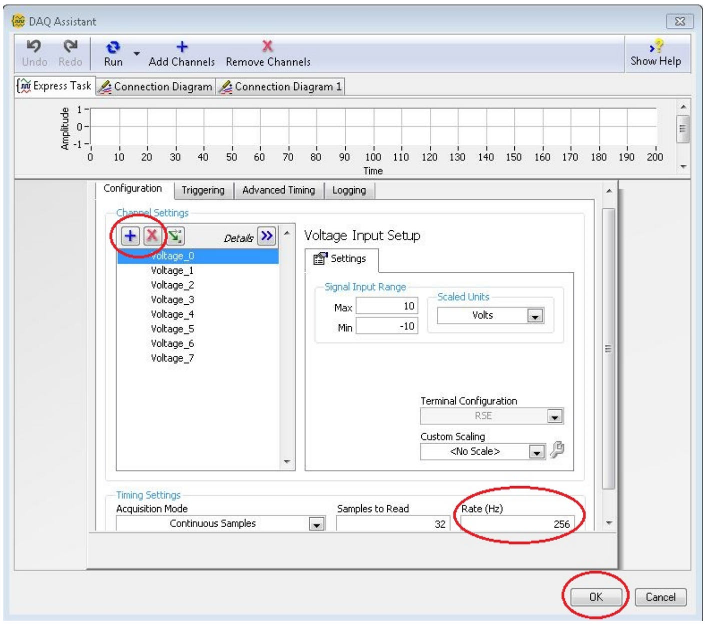
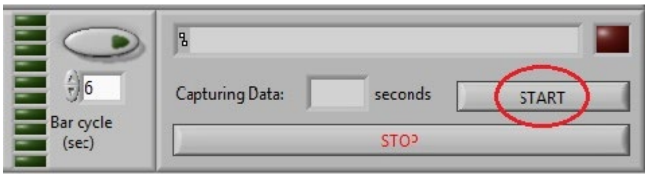


***Figure 3.** DAQ Assistant Settings*

2. **Run** the two .vi files *(**Figure 2.**)*
3. At this point the LED's of the Carelight Sensor should be fully lightened (as shown below) for multi-wavelength illumination. Place the Carelight Sensor against a specific location of a human body (i.e. palm, chest, wrist, back) to obtain the waveforms corresponding to the 4 different wavelength channels and the acceleration.

4. **Adjust** the gain and LED intensity values (for ***DISCO4_A.vi***)until you get the optimum signals *(**Figure 2.**)*
5. **Input** a different file name on the Front Panel in each VI and click **OK** as follows:

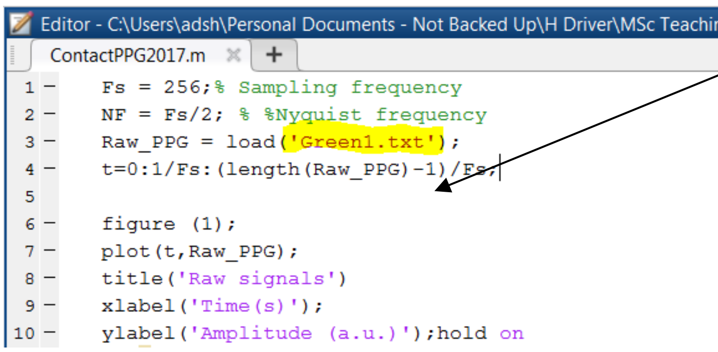
6. Once ready to **record data**, **click START** on either of VI's (***DISCO4_A.vi*** or ***DISCO4_B.vi***) and the recording will automatically start both VI's. Similarly, when you stop recording, both VI's will stop recording and running:



7. Recorded data files will be in the ***Documents > LabVIEW Data*** folder where you can change the name of file to text extension (.txt) and then you will be able to open the file in note pad, Excel or MATLAB.

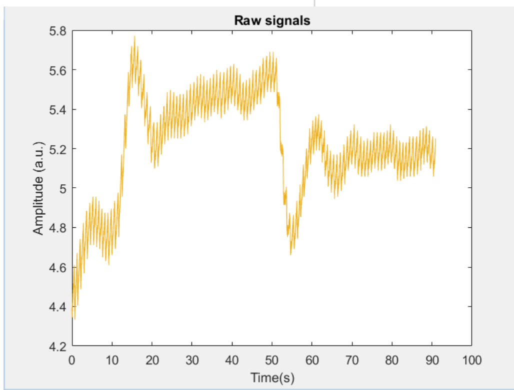
4 Signal Processing

1. Open 'ContactPPG2017' in MatLab and Upload a raw data, i.e. 'Green1.txt',



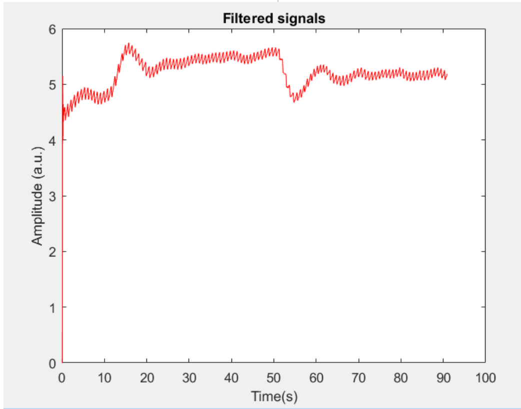

```
Fs = 256;% Sampling frequency
NF = Fs/2; % %Nyquist frequency
Raw_PPG = load('Green1.txt');
t=0:1/Fs:(length(Raw_PPG)-1)/Fs;

figure (1);
plot(t,Raw_PPG);
title('Raw signals')
xlabel('Time(s)');
ylabel('Amplitude (a.u.)');hold on
```

Generate a 'figure (1)' in Raw signals.

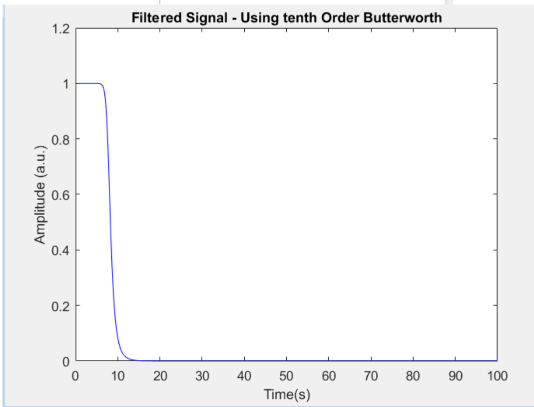


2. Using a Butterworth Filter

```
[a b] = butter(10, 10/NF, 'low'); % generate coefficients of the filter
%filter the noisy from Raw data using the b and a coefficients obtained from the butter filter desig
PPG_filtered = filter(a,b,Raw_PPG); % applied the filter to noisy signal Raw_PPG
hold on
figure(2)
plot(t,PPG_filtered,'r');
title('Filtered signals')
xlabel('Time(s)');
ylabel('Amplitude (a.u.)');
```

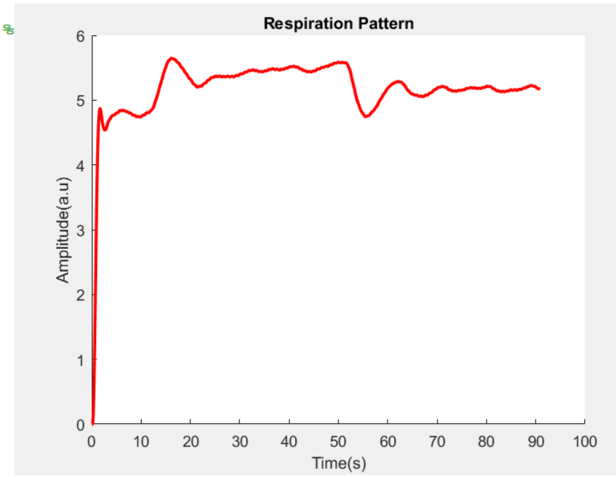



```
figure(3)
% plot the frequency response (normalised frequency)
norm_f = 100*[[0:1/(512 -1):1]];
FR = freqz(a,b);
plot(norm_f,abs(FR),'b');
title('Filtered Signal - Using tenth Order Butterworth')
xlabel('Time(s)');
ylabel('Amplitude (a.u.)');
```



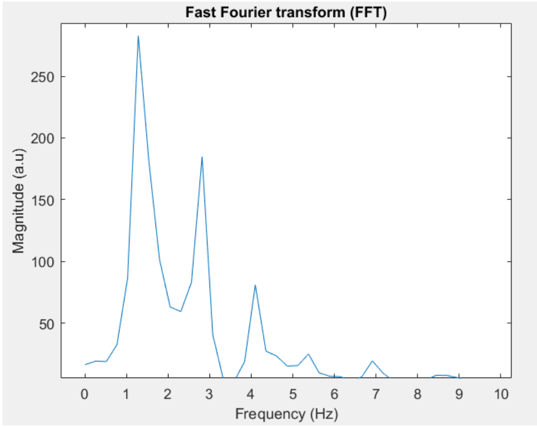
3. Respiration Rate (RR) Filter

```
%%%% Respiration Rate (RR) Filter %%%%%

[ a1, b1]= butter(3,1/Fs,'low') ;
[ x , y]= butter(6,0.4/Fs,'high') ;

[x1,y1]=butter(1,0.09/Fs,'low');

 yabs=abs (PPG_filtered) ;

env = filter( a1 , b1 , yabs ) ;
env1=filter(x1,y1,env);
figure(4);
hold on
plot(t,env,'r','LineWidth',2);
title('Respiration Pattern')
hold on
xlabel('Time(s)');
ylabel('Amplitude(a.u)');
```



4. Spectrum Frequency Domain

```
%%%%%%%%%%%% Spectrum Frequency Domain%%%%%%%%%
 fax_Hz = bin_vals*Fs/N;
 N_2 = ceil(N/2);
 figure(5)
 plot(fax_Hz(1:N_2), X(1:N_2));% plot in magnitude and Hz
 title('Fast Fourier transform (FFT)')
 xlabel('Frequency (Hz)')
 ylabel('Magnitude (a.u)');
```



5. **Pulstile Waveform (filtered PPG signals)**

```
%%%%%%%%%%%% Pulstile Waveform (filtered PPG signals)%%%%%%%%%
figure (6)
plot(t1,ppg)
title('Filtered Signal')
xlabel('Time(s)');
ylabel('Amplitude (a.u.)');
```