Assignment 3

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Applied Signal Processing Laboratory 2023

Introduction

- In this assignment an example of Digital Signal Processing Application to Pulse Oximetry will be covered.
- A pulse oximeter is an instrument that uses two signals emitted by Light-Emitting Diodes at two different frequencies: red and infrared.
- The signals pass through the finger and are received by two photodetectors on the other side.
- The instrument calculates the oxygen saturation (percentage of oxygenated and deoxygenated hemoglobin) by processing the two received signals.
- In the following slides a computation of the oxygen saturation will be found using preexisting data samples taken by an oximeter.

Exercise 3 – Importing sampled data and defining variables

- A ".txt" file containing the pulse oximeter data (red and infrared signal samples) is firstly imported into MATLAB and stored into corresponding variables
- The first 10 seconds of the sampled data is skipped
- Variables used are the following:

Sampling frequency: $\boxed{f_s = 100\ Hz}$

Sampling period: $\boxed{T_s = \frac{1}{f_s} = 0.01\ s}$

Time to skip: $\boxed{T_{skip} = 10\ s}$

Sample to start from:

$$\boxed{sample_{start} = T_{skip} * f_s + 1}$$

Observation window: $\boxed{T = 30\ s}$

Exercise 3 – Applying a low-pass filter

- Since the maximum pulse rate is $180\ bpm$ ($3\ Hz$) due to muscular movement, a low-pass filter is designed and applied to cancel the components above this frequency

- The low-pass filter has been designed as such:

```
H_L = rectangularPulse(-3,3,f_symm);
```

where f_symm is a symmetric frequency axis with respect to which the low-pass filter in the frequency domain is designed

- The Fourier transform has been performed on the Red and Infrared signals after which they are shifter and multiplied with the low-pass filter, consequently cancelling out the frequency components above $3\ Hz$.
- An Inverse Fourier transform is then taken on the resulting filtered signals.

Exercise 3 – Plotting the filtered signals

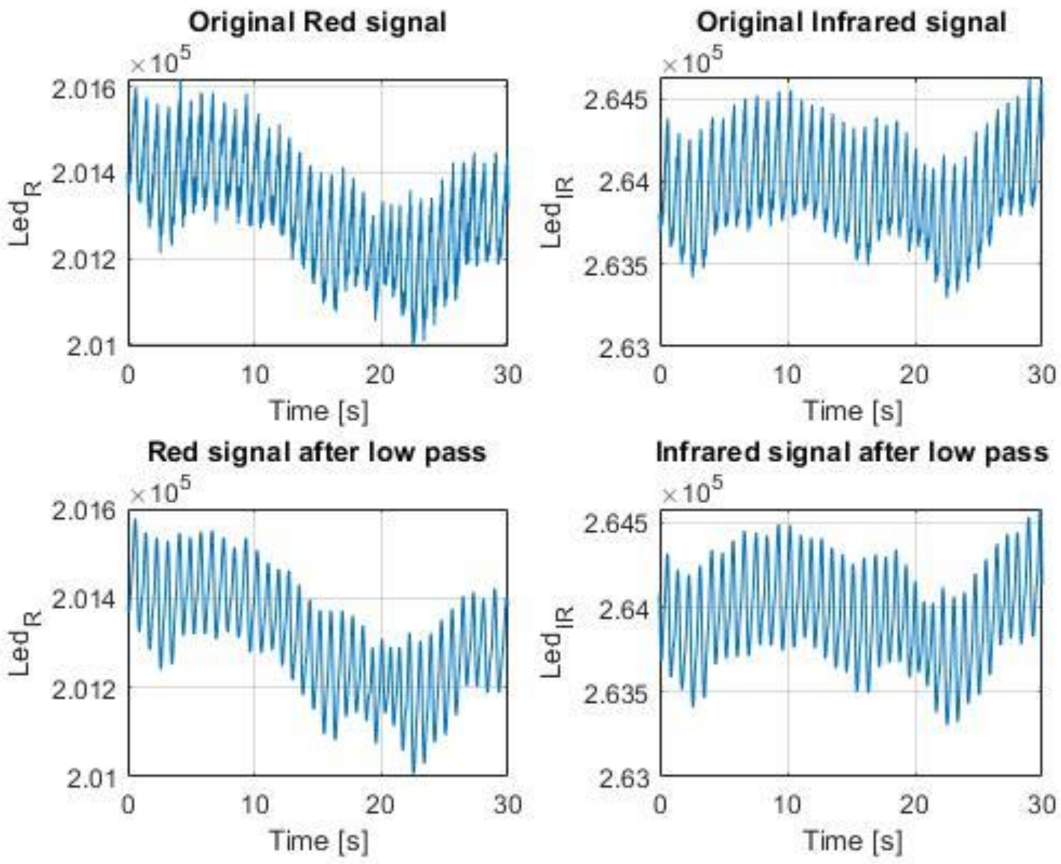

Figure 1.1: Plot of the original red and infrared signals and red and infrared signals after a low-pass filter has been applied

- After plotting the red and infrared signals after a low-pass filter has been applied, alongside the original red and infrared signals, it can be seen that the high frequencies above $3\ Hz$ due to muscular movements have been removed, providing us with a smoother signal (with less rapid time variations)

Exercise 3 – Ratio and saturation formulae

- It is possible to show that the saturation can be computed starting from the measured I_{AC} and I_{DC} signals at Red and Infrared frequencies by applying the following formulae:

Ratio:

$$R = \frac{\frac{I_{AC}(RED)}{I_{DC}(RED)}}{\frac{I_{AC}(INFRARED)}{I_{DC}(INFRARED)}}$$

Saturation:

$$SaO_2 = 110 - 25 * R$$

Where I_{AC} represents the received signal variation due to arterial size change and I_{DC} when the arterial size is at its maximum, therefore the absorption is greater and less signal is received.
Consequently, when the arterial size is at its minimum, the absorption is lower and we receive more signal represented as $I_{AC} + I_{DC}$

Exercise 3 – Computing ratio and saturation in MATLAB

- In MATLAB, the ratios and the saturation are computed with the help of the following MATLAB functions:

```
[pks1,locs1]=findpeaks(LedIRfilt,Time);
[pks2,locs2]=findpeaks(-LedIRfilt,Time);
pks2=-pks2;
HH1=interp1(locs1,pks1,Time,'spline');
HH2=interp1(locs2,pks2,Time,'spline');
```

where $findpeaks$ is a function in MATLAB which returns a vector with the local maxima (peaks) of the input signal vector along with the indices at which the peaks occur

where $interp1$ is a function in MATLAB which returns interpolated values of a 1D function at specific query points using the 'spline' interpolation method

which provides us with the min and max points (of the signals) and performs the interpolation of both respectively.

Exercise 3 – Plotting the interpolating curves and calculating the saturation value

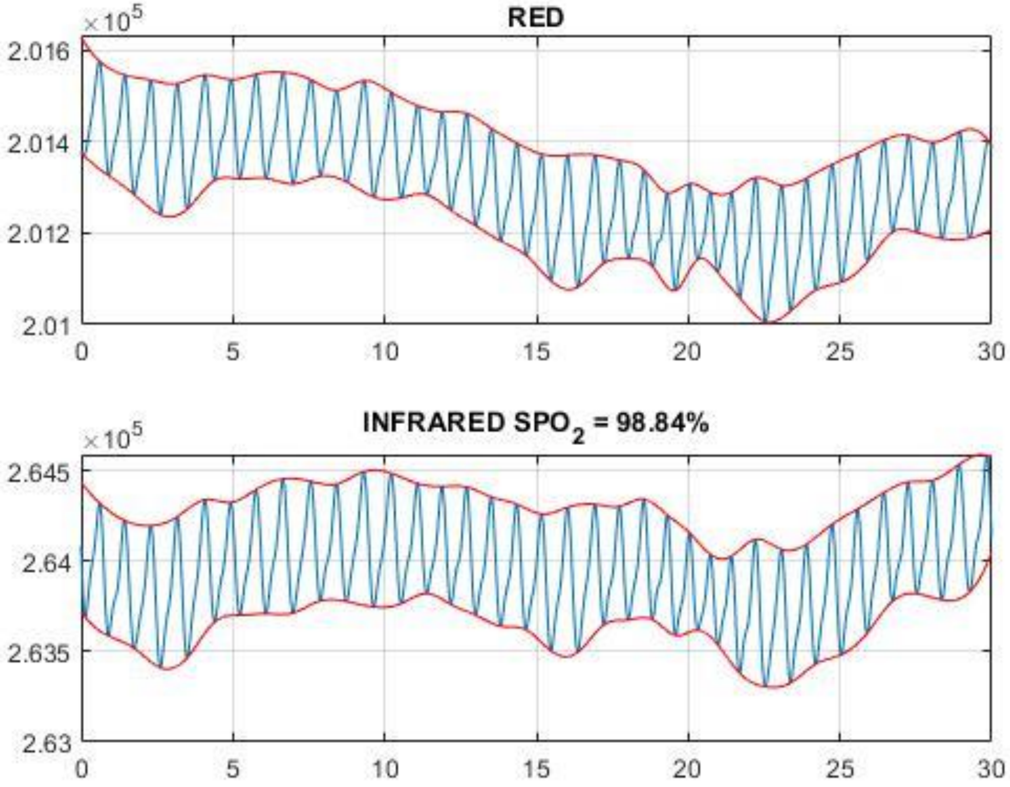

Figure 1.2: Plot of interpolating curves with the saturation value

- In the plots in Figure 1.2 the red lines represent the interpolating curves which help us identify the maximum and minimum values. Using these four red curves, we can compute R at every sample and take its mean to finally find the saturation value.
- In this case, the saturation value is $SPO_2 = 98.84\%$ which was expected

Exercise 3 – Applying a high-pass filter

- The next step is to apply a high-pass filter to cancel the low frequency components due to breathing movements (frequencies below $0.5\ Hz$).
- The high-pass filter designed in the frequency domain will be applied only to the Red signal by taking the product of the filter and the Red signal transformed into frequency domain using the Fourier transform
- The high-pass filter is generated as following:

```
H_H1 = rectangularPulse(-0.5,0.5,f_symm);
H_H = 1-H_H1;
```

Exercise 3 – Pulse rate computation

- To calculate the pulse rate we have to work with the filtered red signal (both the low-pass and high-pass filter applied)
- Using the already introduced function `findpeaks`, the local maxima and their location are found
- The average pulse rate is then found by first computing the differences of all adjacent peak values, finding their mean and lastly normalizing the value found, giving us the result:

$$BPM = \frac{60}{mean_{distance}} = 71.77$$

Exercise 3 – Plotting the filtered signal

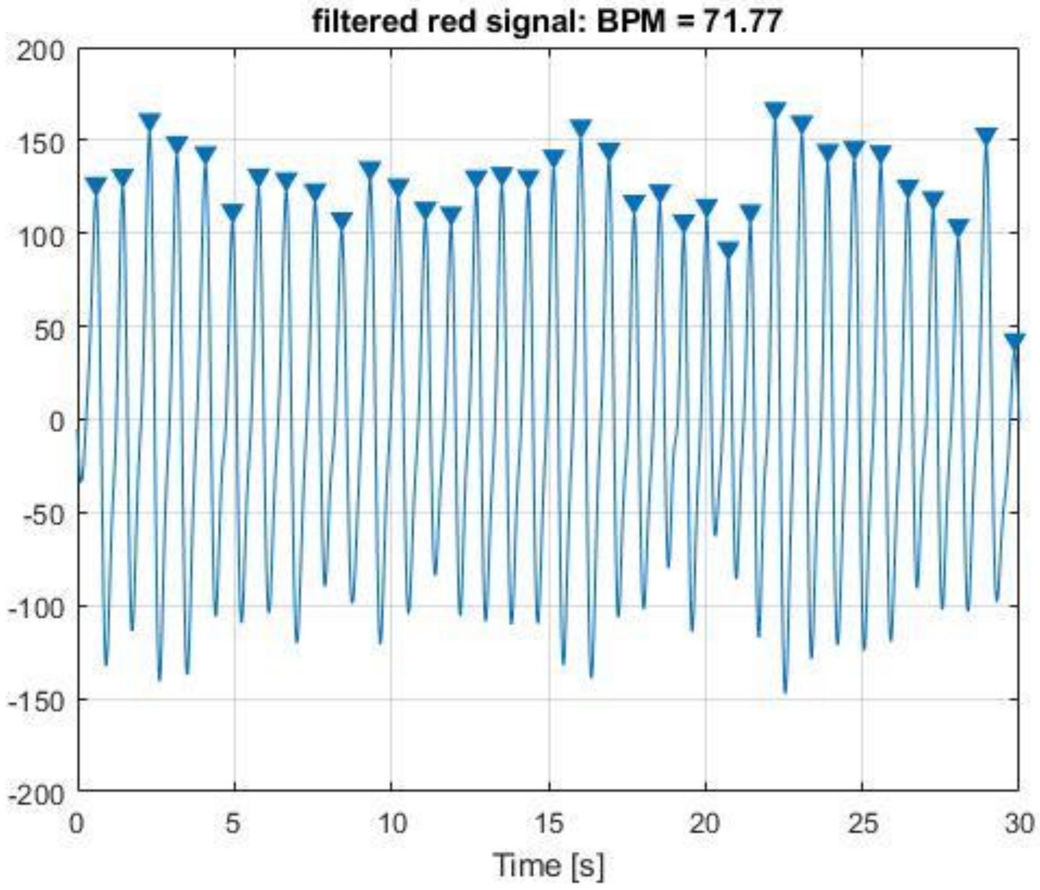

Figure 1.3: Plot of the filtered red signal (with low-pass and high-pass filter applied) with marked local maxima (peaks)

- In Figure 1.3 the filtered red signal can be seen with all the local maxima (peaks) marked. Compared to the signal's behavior before the high-pass filter has been applied, we can observe that the signal is centered around 0 on the y-axis. This is an expected outcome because by applying the high-pass filter, we have eliminated the low frequencies which were high in magnitude, therefore the mean value has shifted towards zero

Exercise 3 – An alternative pulse rate computation

- An alternative way to compute the pulse rate would be by plotting the absolute value of the filtered red signal with respect to the BPM
- The observed window is to be set between $1\ Hz\ (BPM = 60)$ and $1.5\ Hz\ (BPM = 90)$
- The value of the BPM we are looking for can be found by locating the peak (maximum value) and then finding its corresponding BPM at which it is located

Exercise 3 – Plotting the red filtered signal wrt BPM

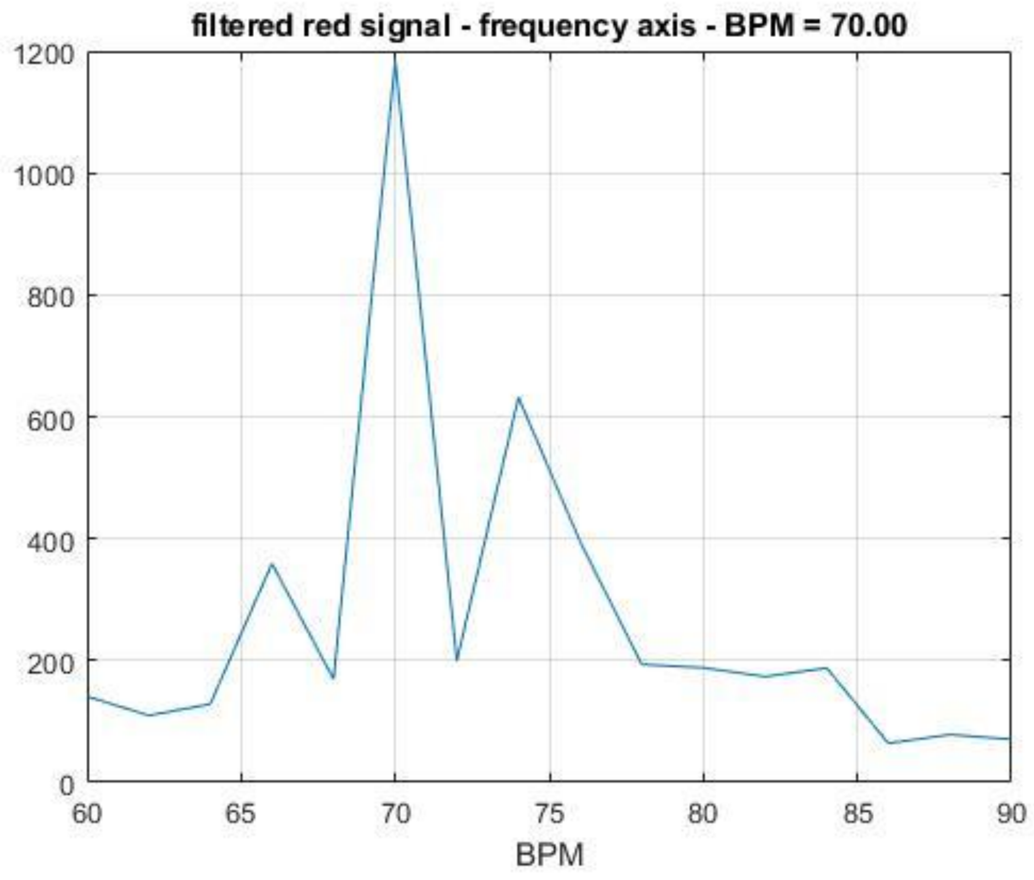

Figure 1.4: Plot of the filtered red signal (with low-pass and high-pass filter applied) with respect to the BPM

- As mentioned before, the peak value corresponds to the value of BPM equal to 70.
- In Figure 1.4 we can observe the presence of three peaks in total. The most prominent peak at 70 BPM corresponds to the heart rate, while the less prominent peaks at 66 BPM and 74 BPM can be due to other factors such as heart rate variability.