POLITECNICO DI TORINO

Electronic and Communications Engineering

Assignment Report 5 - Processing of Bio Signals

Applied Signal Processing Laboratory

01TUMLP

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Exercise 1

The aim of this exercise is to retrieve the heart rate and the blood oxygen saturation ratio expressed in eq.(1), from a set of measurements done with a pulse oximeter.

$$SaO_2 = \frac{[HbO_2]}{[HbO_2] + [Hb]} \tag{1}$$

To find the saturation ratio I applied the following formulas:

$$R = \frac{\frac{I_{AC}(\text{Red})}{I_{DC}(\text{Red}))}}{\frac{I_{AC}(\text{Infrared}))}{I_{DC}(\text{Infrared}))}} \tag{2}$$

$$SaO_2 = 110 - 25R \tag{3}$$

$$\tag{4}$$

where I_{AC} is defined as the component of the signal that is changing according to the arterial size variations and I_{DC} is the continuous component limited by the received signal at maximum arterial size.

Task 1

The data to be analyzed is taken from a set of 11564 measurements performed with an acquisition rate of $f_s = 100Hz$. I took a time interval of 60 seconds, from $10s$ to $70s$ to discard the initial transient. Figure 1 illustrates the acquired signals relative to the detected infrared (IR) and red (R) lights.

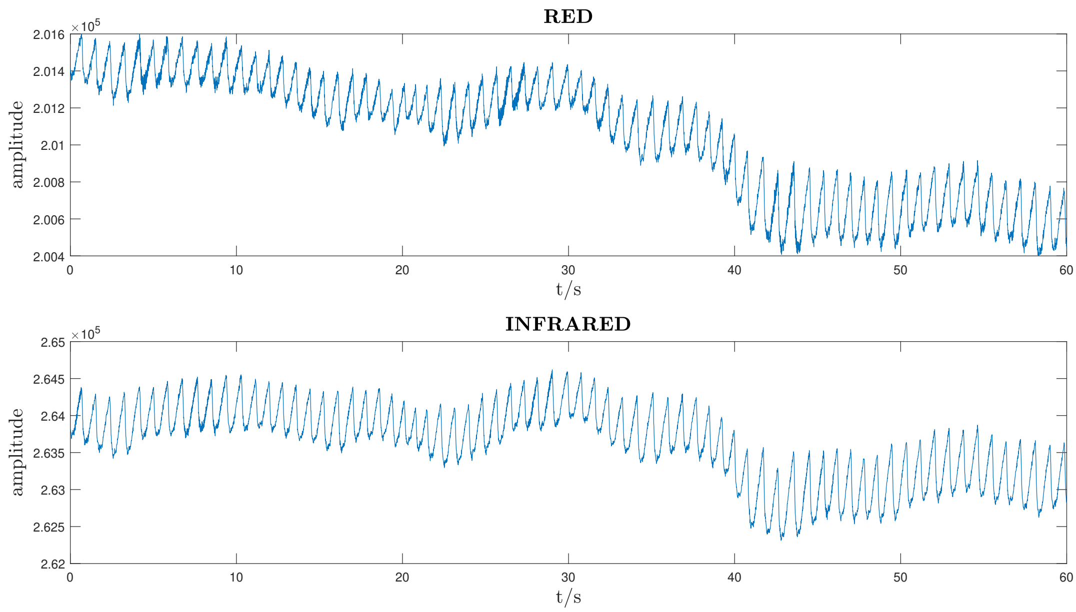
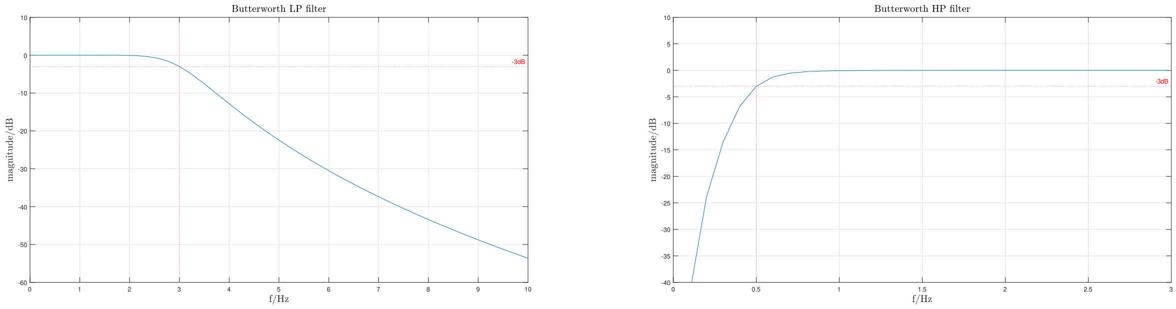


Figure 1: Exercise 1 - *Oximeter output signals*

Task 2

As it can be seen from Figure 1, the signals have some disturbances at higher frequencies related to noise and to the muscular movement. To filter these disturbances I applied a Butterworth low-pass filter of the fifth order with the $-3dB$ cuf-off frequency at $3Hz$. To design the filter I used the `butter` function from which I obtained the frequency response shown in Figure 2.(a).

To reduce also the disturbances at low frequencies related to the breath movements, I designed in a similar way a Butterworth high-pass filter of the third order with cut-off frequency at $0.5Hz$. The frequency response of the high-pass filter is shown in Figure 2.(b).
I used the Butterworth filter since it has the flattest frequency response in the pass-band, leaving the interested bandwidth almost unchanged.



(a) *Low-pass Butterworth filter with* $f_c = 3Hz$ (b) *High-pass Butterworth filter with* $f_c = 0.5Hz$

Figure 2: Exercise 1 - *Frequency response of the filters*

Task 3

Form Figure 3 it can be seen the effect that each filter has on the signals: the low-pass filter heavily reduced the high frequency ripples and the high-pass filter cut the DC component so that the signals are now centered around the zero axis.

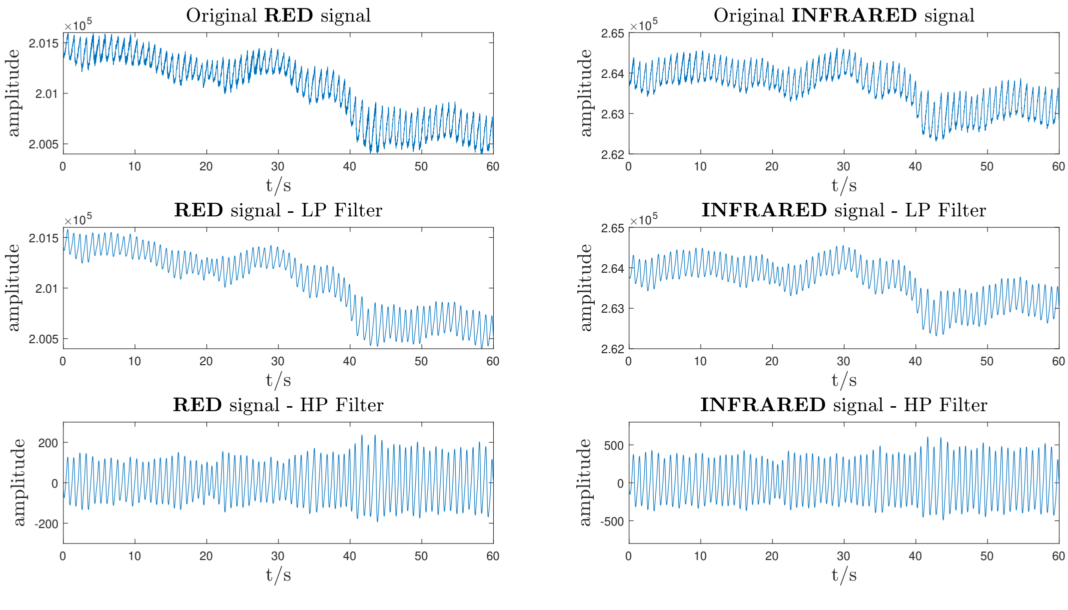


Figure 3: Exercise 1 - *Filtered signals*

Task 4

To compute the pulse rate I first applied the function findpeaks to detect the peaks in the filtered signal related to the red light (Figure 4). Then I summed all the time intervals contained in each pair of consecutive peaks and I divided the result by the total number of intervals to obtain the mean value $\overline{T}$. I obtained the following value of the pulse rate f_H:

$$f_H = \frac{60s}{\overline{T}} = 70.9699\ bpm$$

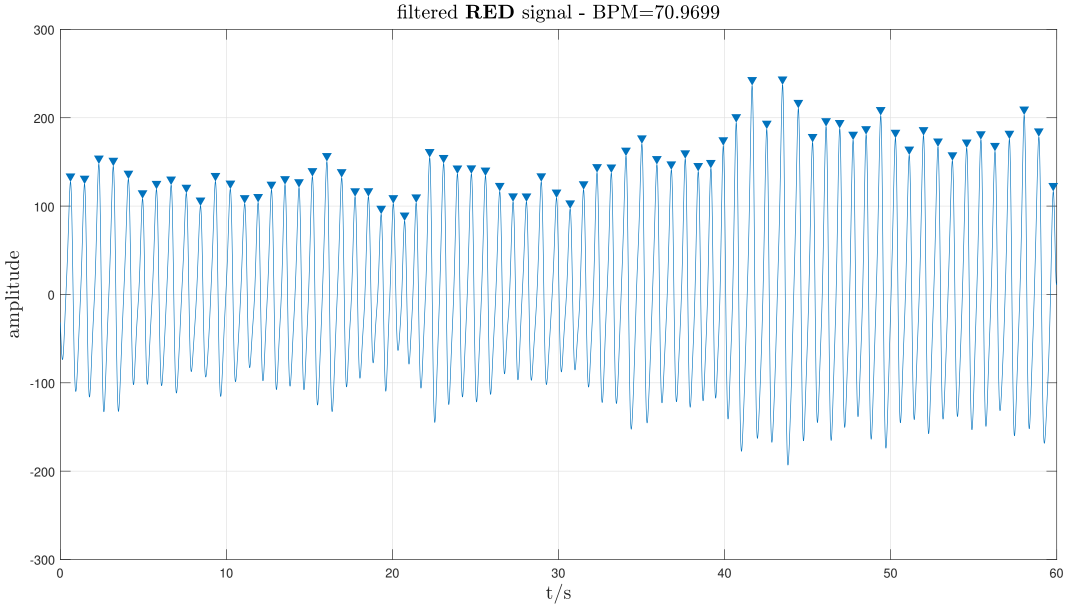


Figure 4: Exercise 1 - *Peaks of the red light signal*

Task 5

Finally, to evaluate the saturation coefficient in eq.(3) I first computed the average value of the ratio R in eq.(2) for each second. To find I_{AC} and I_{DC} I interpolated the peaks to get the red curves depicted in Figure 5 and resampled them at frequency $f = 1Hz$ applying Matlab resample function. The values of I_{DC} coincide with the resampled curves that interpolate the lower peaks in the low-pass filtered signals, whereas the values of I_{AC} coincide with the difference between the upper and lower resampled curves of the band-pass filtered signals.
After computing the mean value of the ratio R, discarding the endpoints of the interpolating curves, I obtained the following value of the blood oxygen saturation:

$$Sa0_2 = 98.1664\%$$

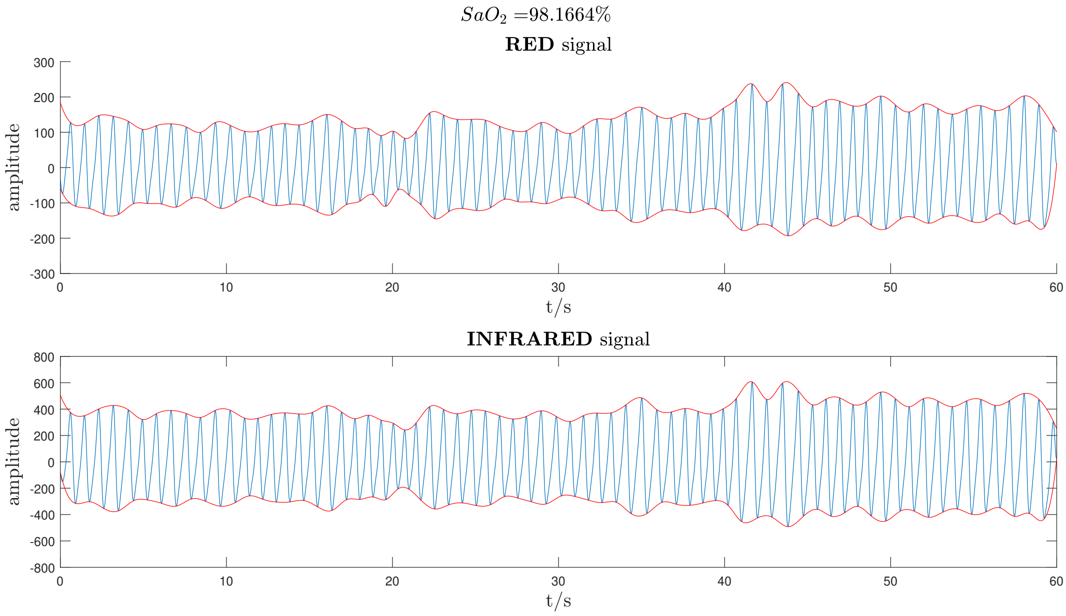


Figure 5: Exercise 1 - *Interpolating curves*

Exercise 2

The main objective of this exercise is to retrieve the thickness of the corneal layers from an image acquired by means of OCT (Optical Coherence Tomography) technique.

Task 1

The tomogram to be analyzed is a $640x1016$ pixels grayscale image (Figure 6).

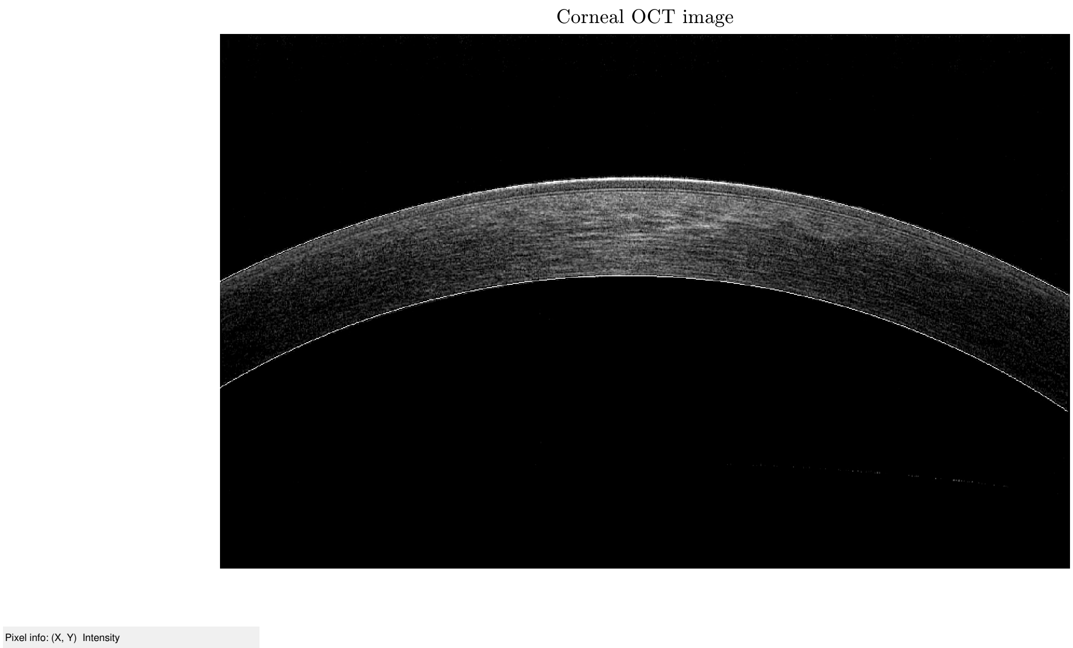


Figure 6: Exercise 2 - *OCT image of the corneal layers*

Task 2

To find the coordinates of the upper layer, I looked for the first full white pixel (255) using the function find, then I looked for the last white pixel along the same row, and I averaged the two values to find the x coordinate of the corneal axis, x_1. The coordinates that I found for the upper boundary of the Epithelium region along the corneal axis are $(x_1, y_1) = (495, 173)$.

Task 3

To find the corneal radius, I first identified a second point $(x_A, y_A) = (248, 204)$ where x_A is the ceil of $x_1/2$ and y_A is the y-coordinate of the first white pixel found in the vertical line x_A. Then I obtained the radius r of the cornea applying the Pythagorean theorem as follows:

$$r^2 = (r - (y_A - y_1))^2 - (x_1 - x_A)^2$$
$$r = \frac{(x_1 - x_A)^2 - (y_A - y_1)^2}{2(y_A - y_1)}$$

From this calculation I found that the radius is approximately 1000 pixels long (corresponding to $4130\mu m$) with center at $(x_c, y_c) = (495, 1172)$.

Task 4

I computed the mean intensity values by evaluating the mean value of the pixels in each sub row, that goes from pixel $x_1 - 25$ to pixel $x_1 + 25$. The central region and the mean intensity vector are shown in Figure 7.

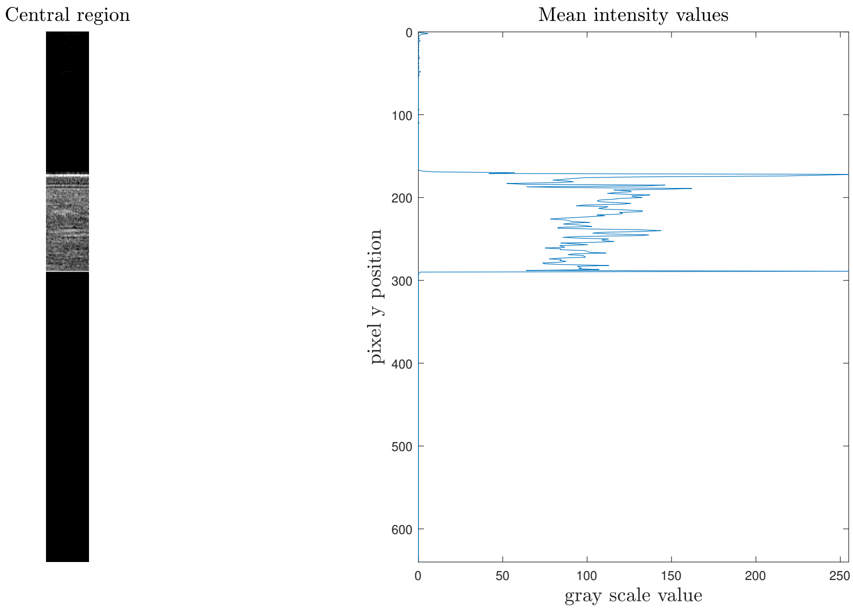


Figure 7: Exercise 2 - *Central region and mean intensity values*

Task 5

The cornea is limited at the top from the Epithelium, whose coordinates on the central axis are (x_1, y_1), and at the bottom from the Endothelium. To find the the y coordinate of the latter on the corneal axis, I looked for the second layer characterized by full white pixels. Then, I found the first three absolute minima of the mean intensity values applying the function islocalmin to find the position of the boundaries of the inner layers. The plot in Figure 8 shows the values of the y-coordinates, highlighted on the mean intensity vector.

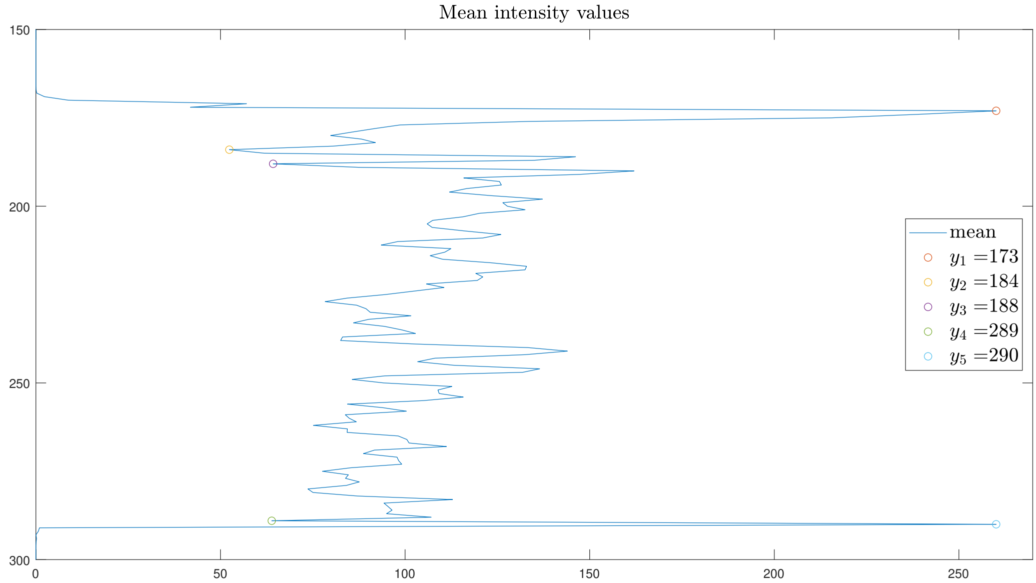


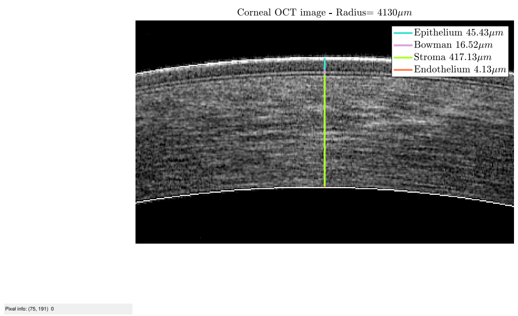
Figure 8: Exercise 2 - *Position of the different regions*

Task 6

With the coordinates found in Task 5, I computed the thickness of each layer as $y_i - y_{i-1}$. The final results are shown in Figure 9.(a) in pixels and in Figure 9.(b) in μm.

$$\text{Epithelium} = 45.43\mu m$$
$$\text{Bowman} = 16.52\mu m$$
$$\text{Stroma} = 417.13\mu m$$
$$\text{Endothelium} = 4.13\mu m$$

(a) *Corneal layers in pixel length*



(b) *Corneal layers in μm*

Figure 9: Exercise 2 - *Corneal layers*