1st Project Neuroinformatics

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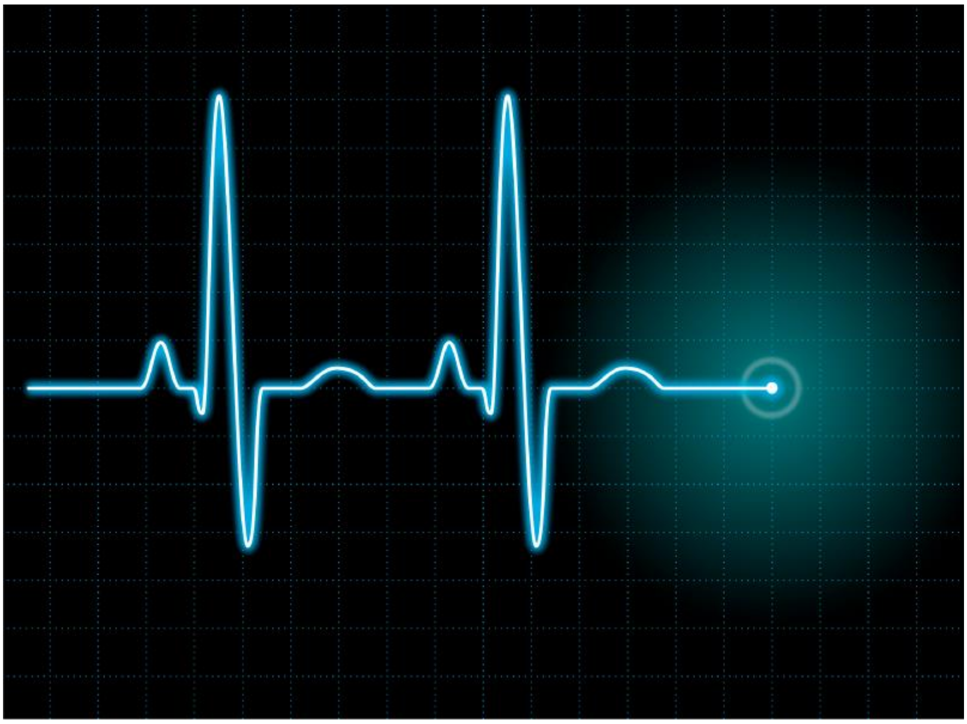

Figure 1. Reference: https://findbiometrics.com/samsung-aims-for-biosignal-authentication-23311/

Introduction:

In this project, we will perform various analyzes such as spectral analysis, application of different types of filters (FIR, IIR), transformation Fourier and ICA to biosignals.

The project consists of 5 different tasks which are as follows:

1: Use Matlab command-line functions (from script [1]) to perform spectral analysis of the signals listed below:

- a) a cardiac signal, using ‘’load ecgsig.mat ‘’(Fs=360 Hz).
- b) Near-infrared spectroscopy (NIRS) data obtained from two human subjects. Use “load NIRSData” to read the two signals (Fs=10 Hz), then isolate them as x1 and x2 and compare the brain activity between participants.
- c) A signal of Optoacoustic emissions (OAEs), using ‘’load dpoae’’ to read the signal (Fs=20 kHz)

2: Repeat the above task, using the Signal Analyzer app.

3: Based on the script [4], experiment with changes in the order of the used filter and demonstrate/comment on what is the role of the filter’s order parameter.

4: Based on the script [5], compare the effects of the two different types of filters (FIR vs IIR). Which is preferable? Can you make the FIR filter as effective as the IIR filter?

5: Run script [7] and describe the obtained results. What is the reason for performing ICA? Are the results always the same? Run ICA on a subsample of sensors and compare the results with the ones obtained from the whole set of sensors.

Implementation:

1:

In the first script a representation is made of: data concerning time, the result of applying the Fast Fourier Transform (FFT) (from time to frequency), the spectrum with a periodogram where the signal is cut into equal chunks of a specific duration, and finally the estimation of the Power Spectrum Density (PSD) by the technique pwelch. This technique defines the power signal density as a frequency function and uses the welch to calculate the power spectrum.

A:

In the first subquery by changing the data entered in Script 1, the sampling frequency (fs) from 50 to 360, the range of the x lim from 25 to 180 (half the sampling frequency) and by entering the commands x = ecgsig, xm = x – mean (x);, we get the following results:

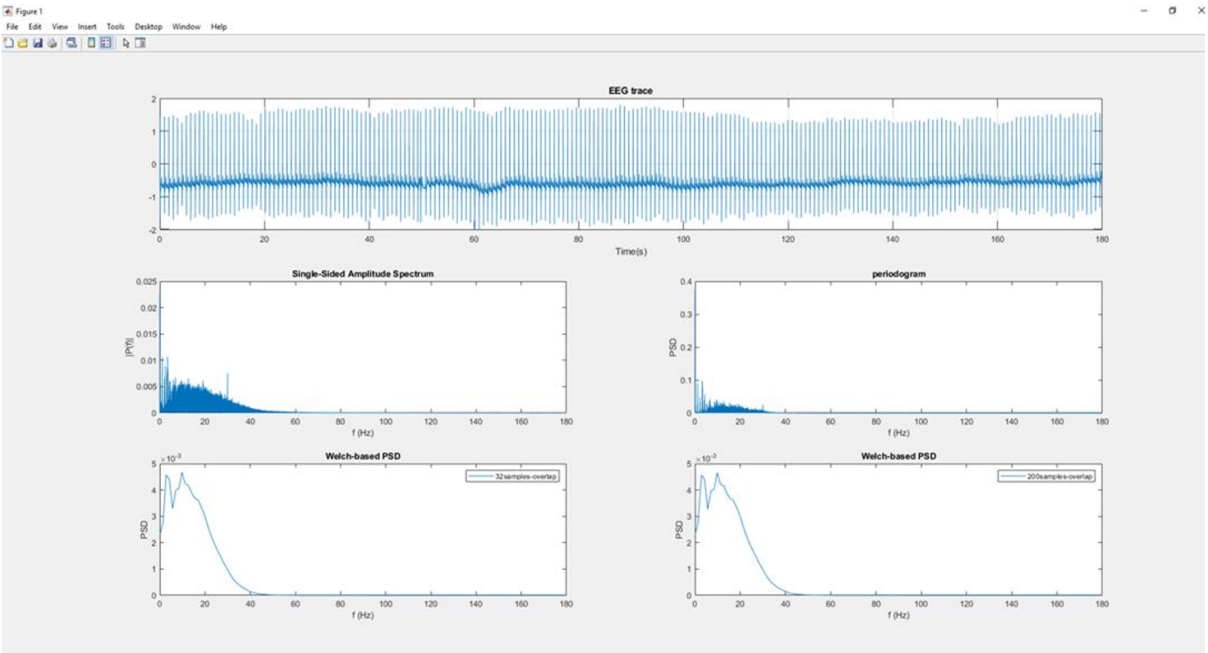

Figure 2. Spectral analysis for ECG

In the graphs we observe the electrocardiogram signal, one of the two frequency values after the Fast Fourier Transform, as long as they are symmetric, the periodogram and Welch based PSD for 32 and 200 samples.

B:

NIRS: is a spectroscopic method that uses the near-infrared region of the electromagnetic spectrum (from 780 nm to 2500 nm). Typical applications include medical and physiological diagnostics and research including blood sugar, pulse oximetry, functional neuroimaging, sports medicine, elite sports training, ergonomics, rehabilitation, neonatal research, brain-computer interface, urology (bladder contraction), and neurology (neurovascular coupling) (Wikipedia).

In this subquery, we have two different signals from two different people. Therefore, we will perform spectral analysis separately for the two signals By changing the data (NIRSData), sampling frequency (fs) from 360 to 10 and changing the value of limx from 25 to 5, produced the following graphical results for two signals:

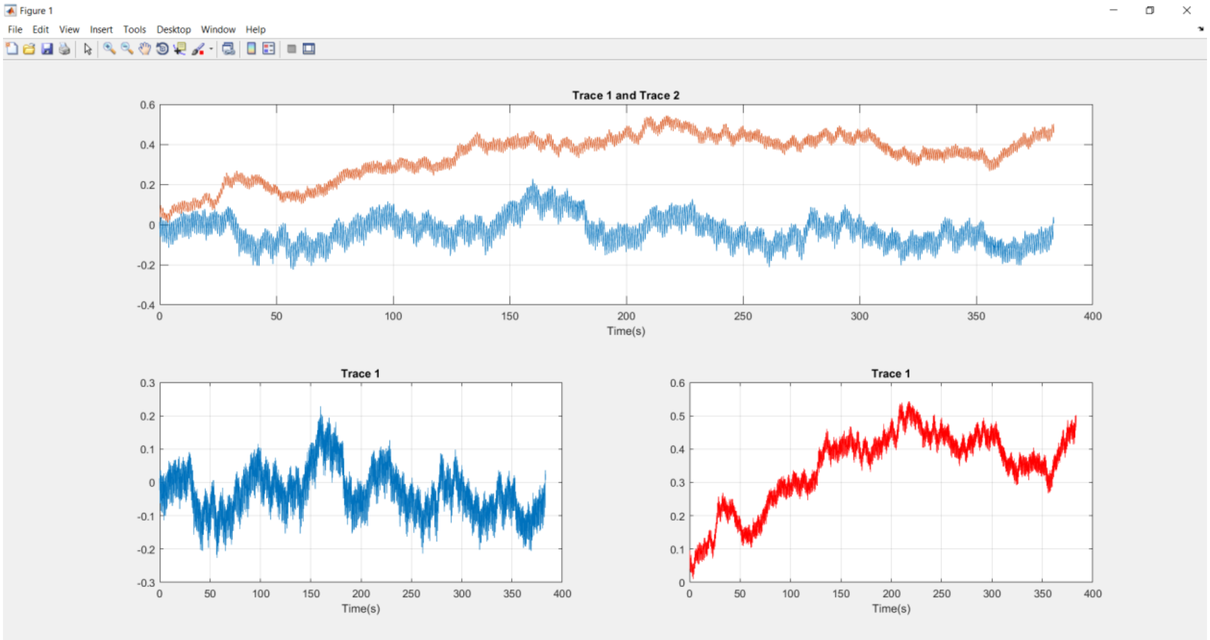

Figure 3. Near-infrared spectroscopy (NIRS) data obtained from two human subjects.

The signals produced by the brain belong to two different people. The red color represents the first person's signal and blue, the second person's signal.

We observe that over seconds the two signals have a large difference in width. This means that one of the two people had higher brain activity (task, focus).

To separate the two different signals, we use the following code:

```
load NIRSData;

figure plot(tm, NIRSData(:,1));

hold on;

figure;

plot(tm, NIRSData(:,2),'r');

legend('X1','X2','Location','NorthWest');

xlabel('Seconds');

tittle('NIRS Data');

grid on;

hold off;
```

Separation gives the following graphs for two different people:

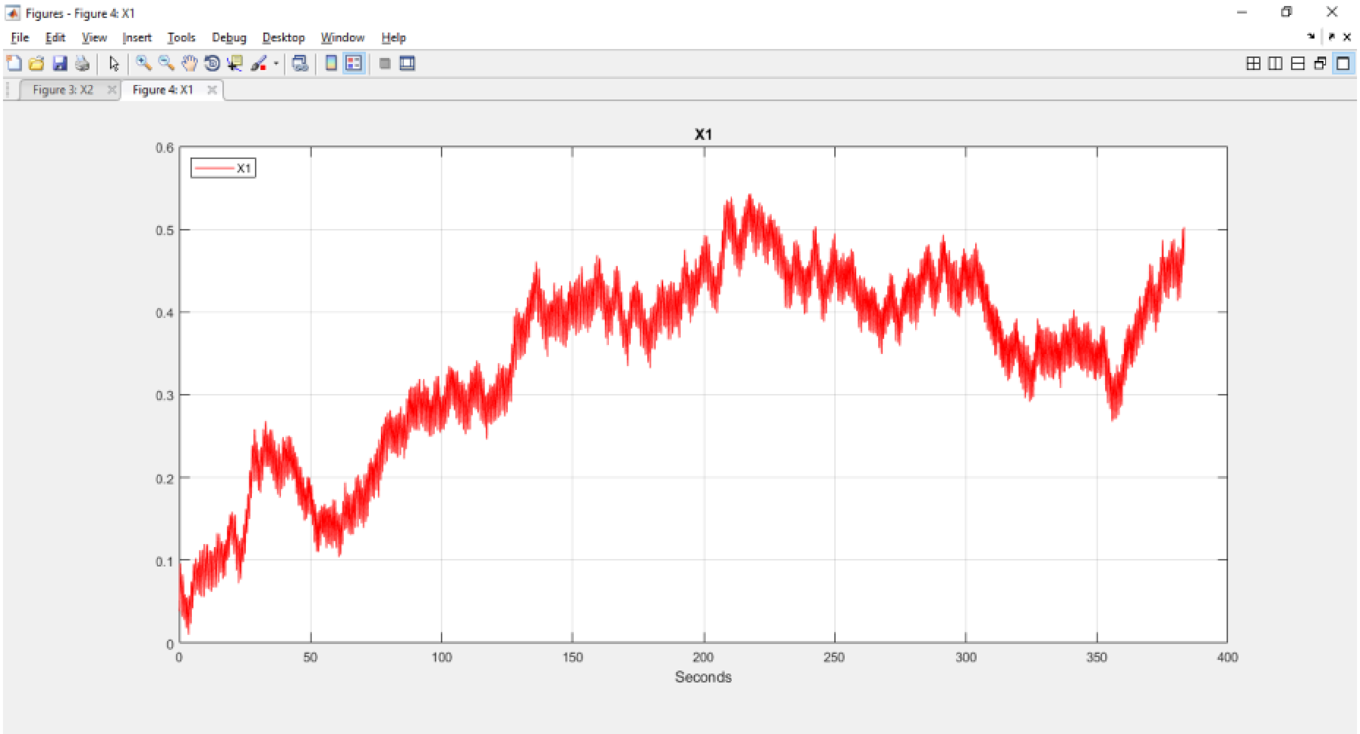

Figure 4. NIRS from first person.

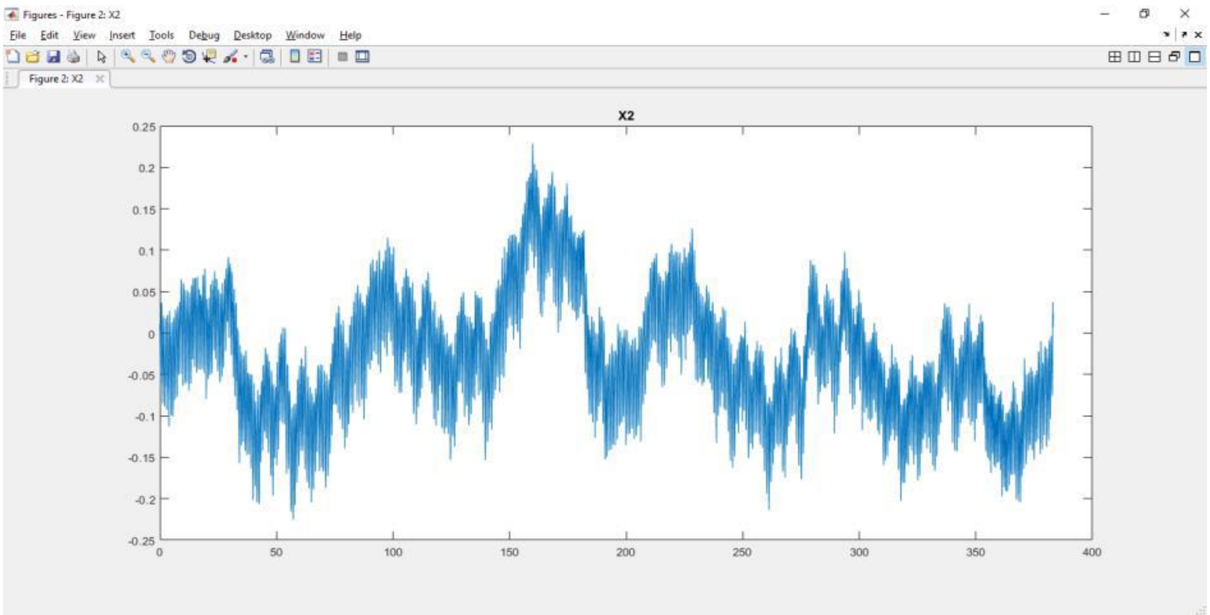

Figure 5. NIRS from the second person.

The spectral analysis for the two signals separately is as follows:

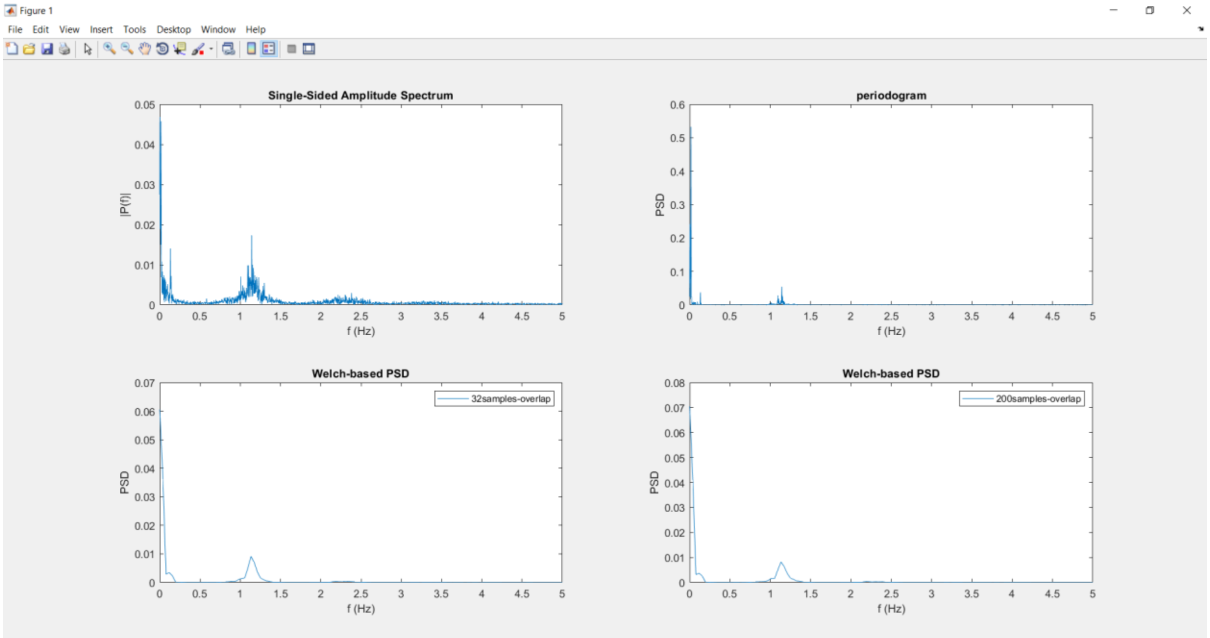

Figure 6. Spectral analysis for the first person.

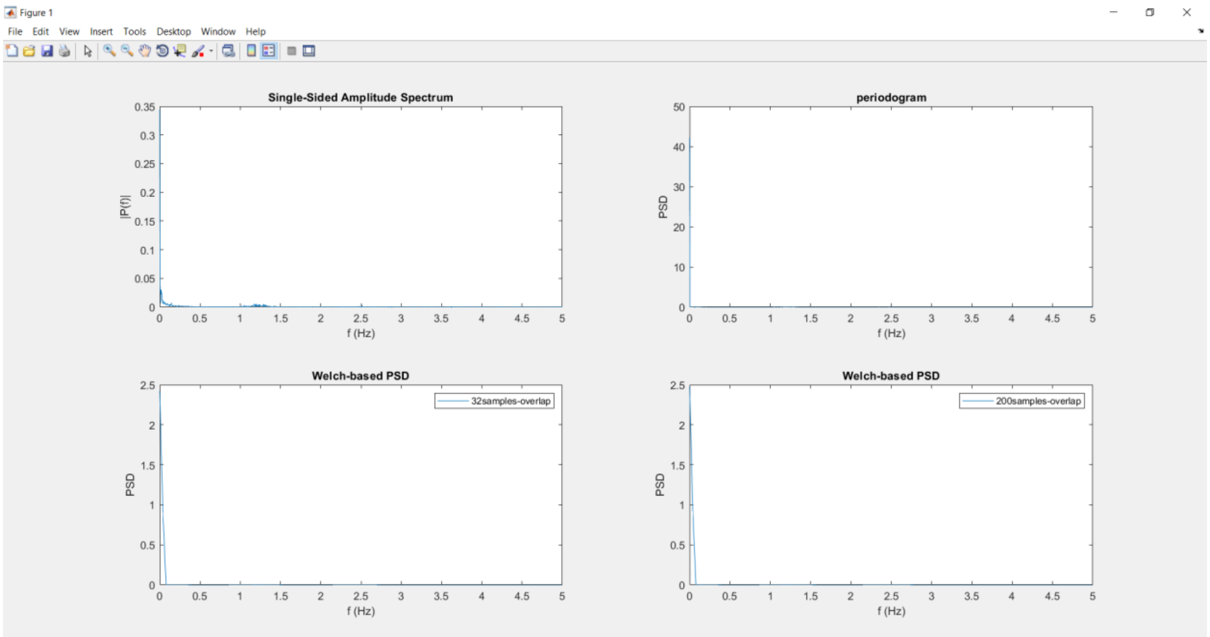

Figure 7 Spectral analysis for the second person.

From the graphs of the spectral analysis, it seems that one person has more brain activity than the other.

C:

An otoacoustic emission (OAE) is a sound that is generated from within the inner ear. Studies have shown that OAEs disappear after the inner ear has been damaged, so OAEs are often used in the laboratory and the clinic as a measure of inner ear health. Broadly speaking, there are two types of otoacoustic emissions: Spontaneous otoacoustic emissions (SOAEs), which can occur without external stimulation, and evoked otoacoustic emissions (EOAEs), which require an evoking stimulus (Wikipedia).

For the last subquery by changing the data (dpoae), sampling frequency (fs) from 10 to 20000 and changing the value of limx from 5 to 10000 produced the following graphical results:

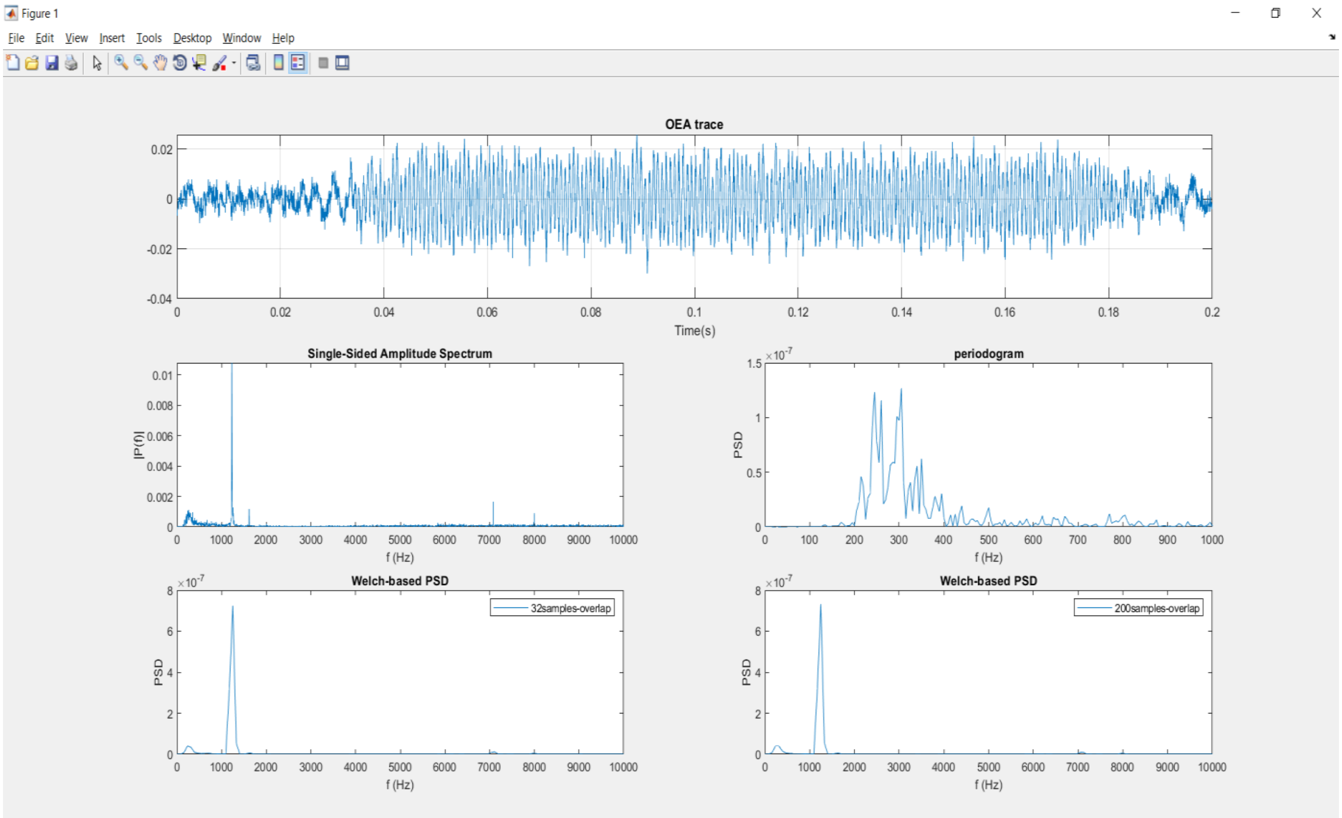

Figure 8. Spectral analysis for a signal of otoacoustic emissions.

In the first graph is represented by the original signal, in the second we observe a fairly high frequency after the Fourier transform, in the third, it shows the frequency variation in the periodic graph and the following two graphs it shows the frequency based on Welch PSD for 32 and 200 samples

2:

To apply the same procedures of the first query I used the Matlab application named Signal Analyzer.

A:

For the first part, I added the original signal to the signal analysis application and with the application power spectral and frequency, I showed the following graphic results:

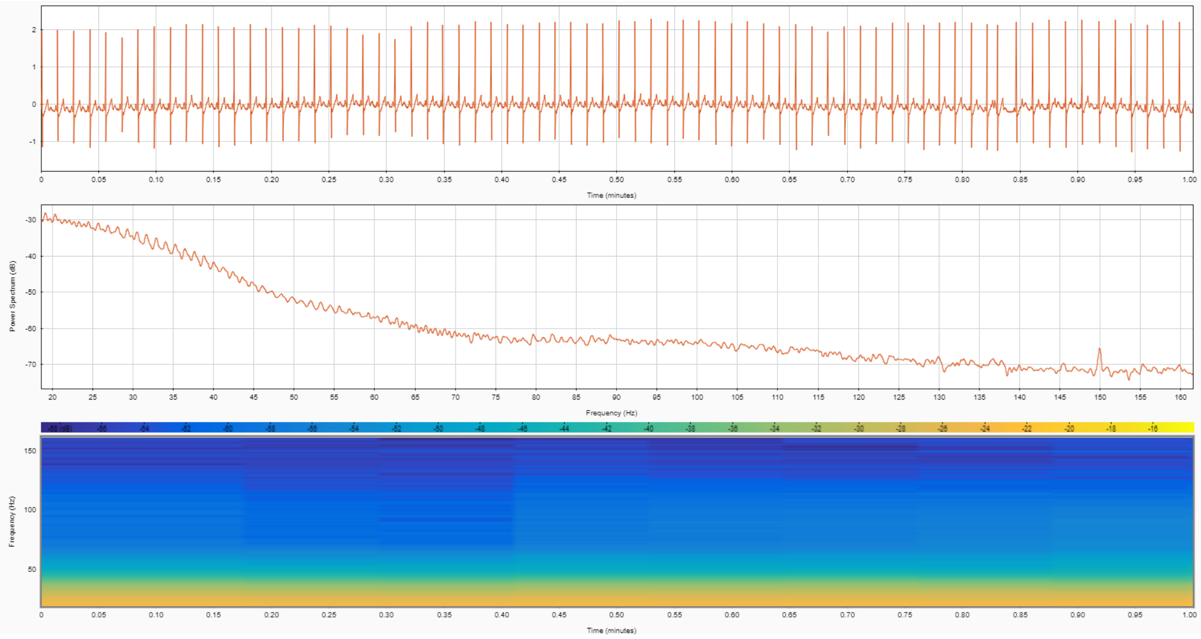

Figure 9. Spectral analysis for ECG

B:

For sub-question b it follows:

In this section, I added the original signals from two different people together and showed the spectral power aw shown below:

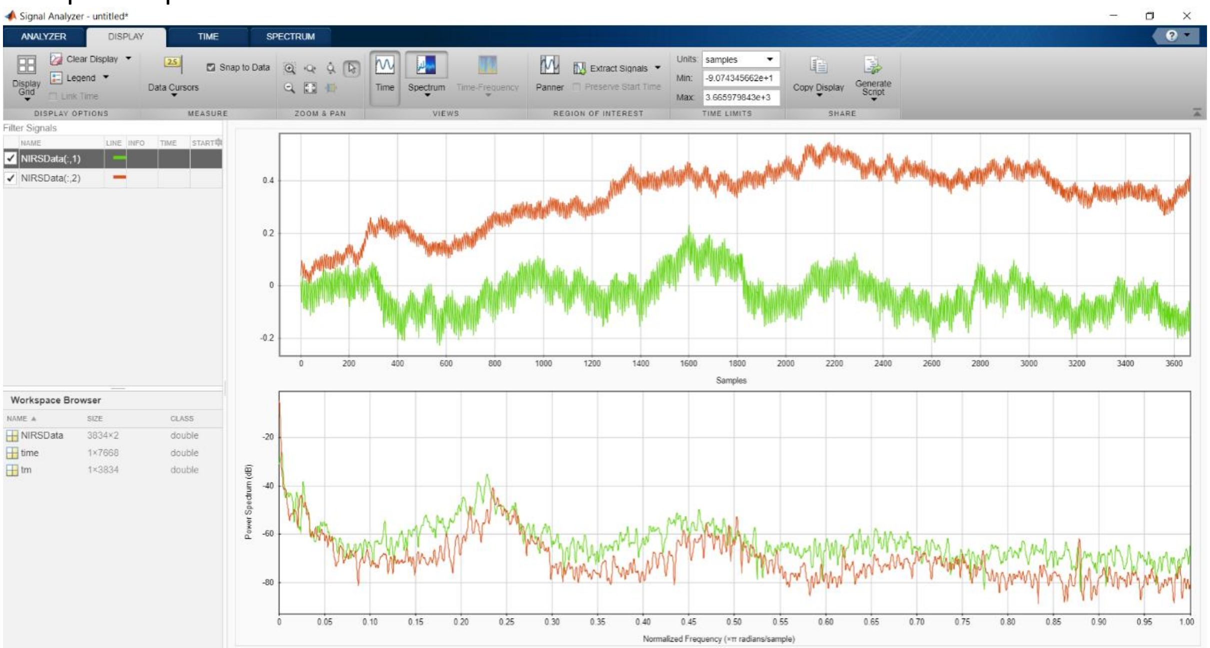

Figure 10. The two signals in the same window.

Then I separated the two signals and showed their frequency to complete the spectral analysis.

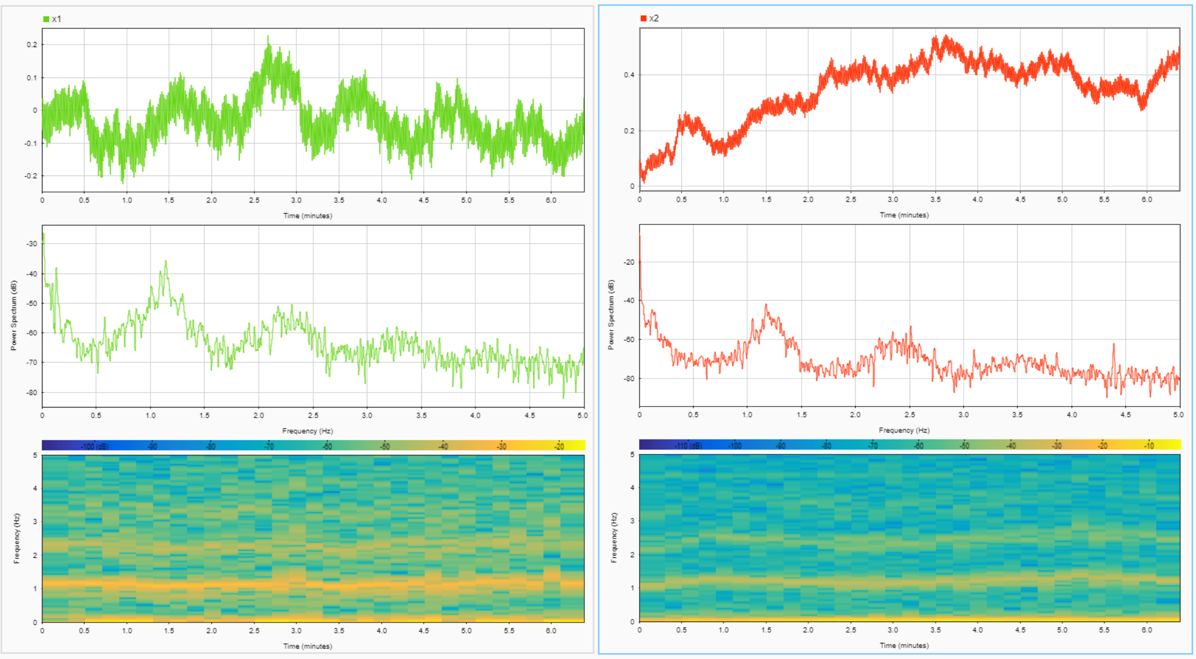

Figure 11. NIRS data obtained from two human subjects in two different windows.

C:

In the last section after adding the original signal to the analyzer app, I showed the frequency and power spectral:

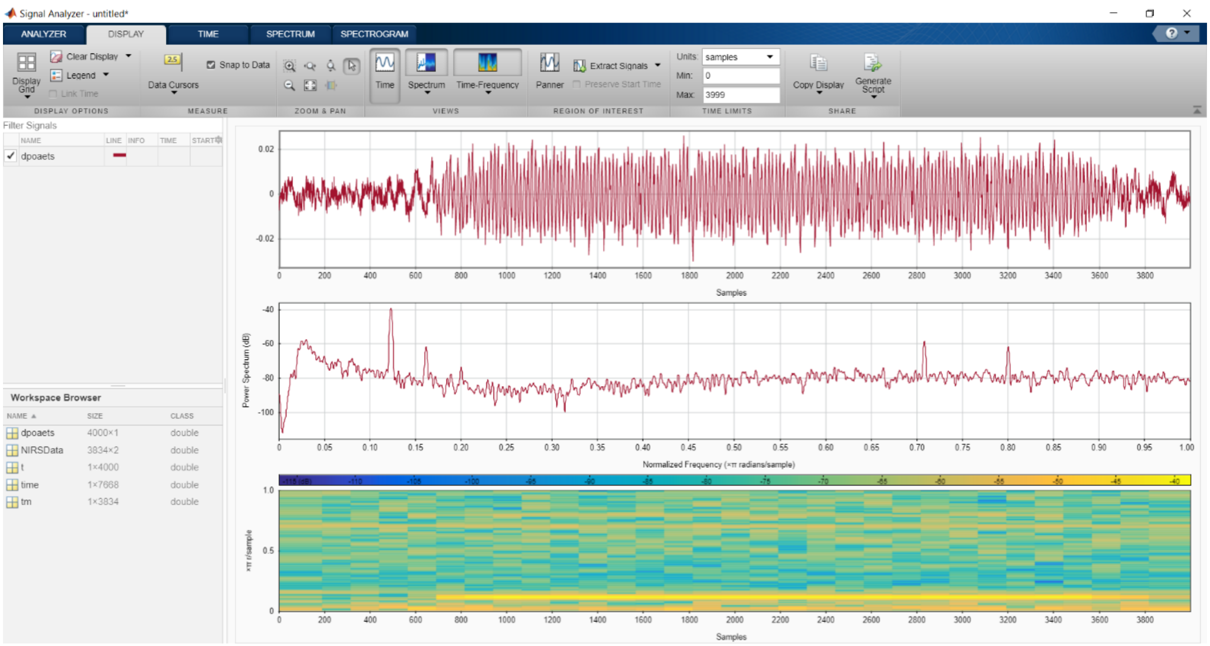

Figure 12. Spectral analysis for a signal of otoacoustic emissions.

3:

In the third task those implemented by the code are the following: load data, illustration of heart signal, design a high-pass FIR 32-order filter with a cutoff at 8 Hz, apply the filter in causal (forward-direction) mode and apply the filter in zero-phase mode.

The result after running the corresponding script is shown below:

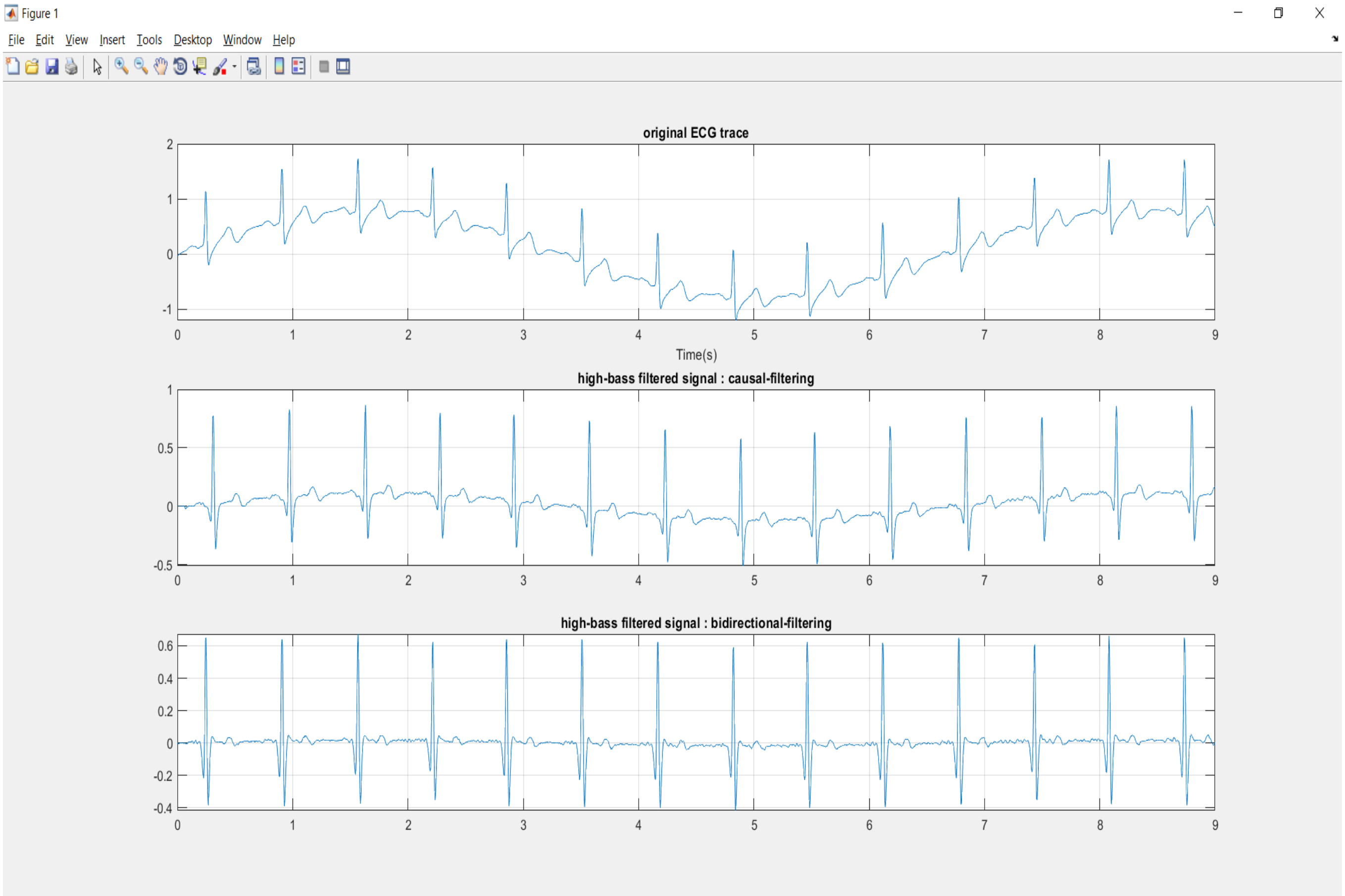

Figure 11. Applying filters to an original ECG.

We observe the differences between the three graphs. The difference between the first two signals is in phase and amplitude of the signal as the original signal before it is filtered has a variation in amplitude (respiration). I also note that the third graph compared to the second graph has a constant width as we observe that it has the same value over seconds (the breath has disappeared) and starts with zero phases.

Changing the high filter order from 32 to 256 produces the following graphs:

Note: Filter order is the maximum delay, in samples, used in creating each output sample is called the order of the filter.

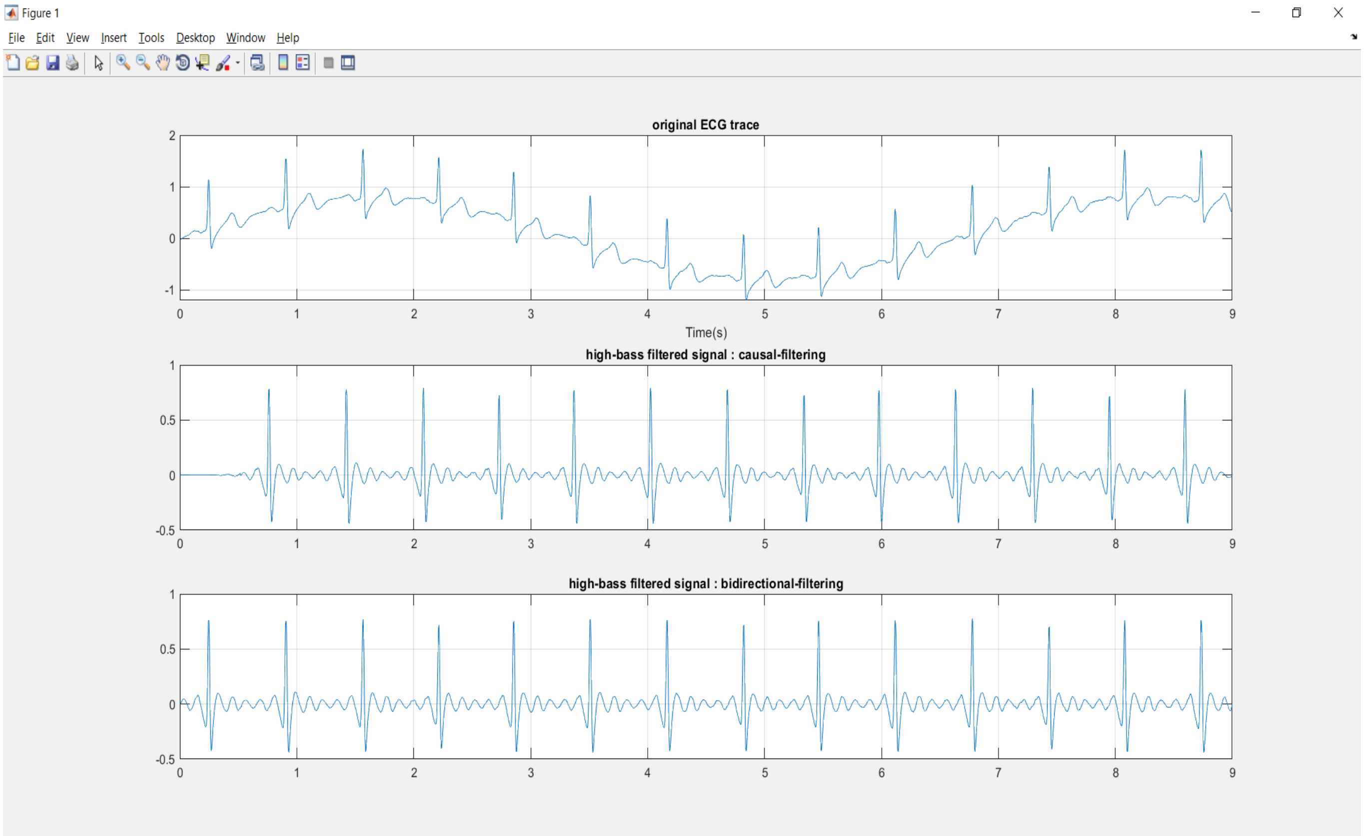

Figure 13. Applying filters with a different order to an original ECG.

There seems to be a delay in the signal and also the noise that infects our signals. So, the order of the filter can directly affect the phase of a signal, the noise that infects the signal,

The order of a filter represents the order of the differential equation describing the filter. This, in turn, depends on the number of roots of the characteristic equation of the differential equation (which is nothing but the number of poles of the filter). Poles represent the number of resonant/natural frequencies of the system.

Generally, the higher the order, some combination of the following can be achieved:

- more attenuation between the passband and stopband
- narrower transition band
- flatter passband (less ripple)

On the other hand, these are the price you may pay:

- more compute-intensive
- higher resource cost (SW or HW)
- longer group delay
- high chance for instability in case of IIR filters
- higher dynamic range requiring more costly data format: single precision to double precision, integer to floating points.

4:

In this task those that are implemented are the following: load data, illustrate the original signal, design a stop-band FIR 36-order filter for removing power line noise and design and stop-band IIR 3-order filter for removing power line noise. The graphs that are exported are as follows:

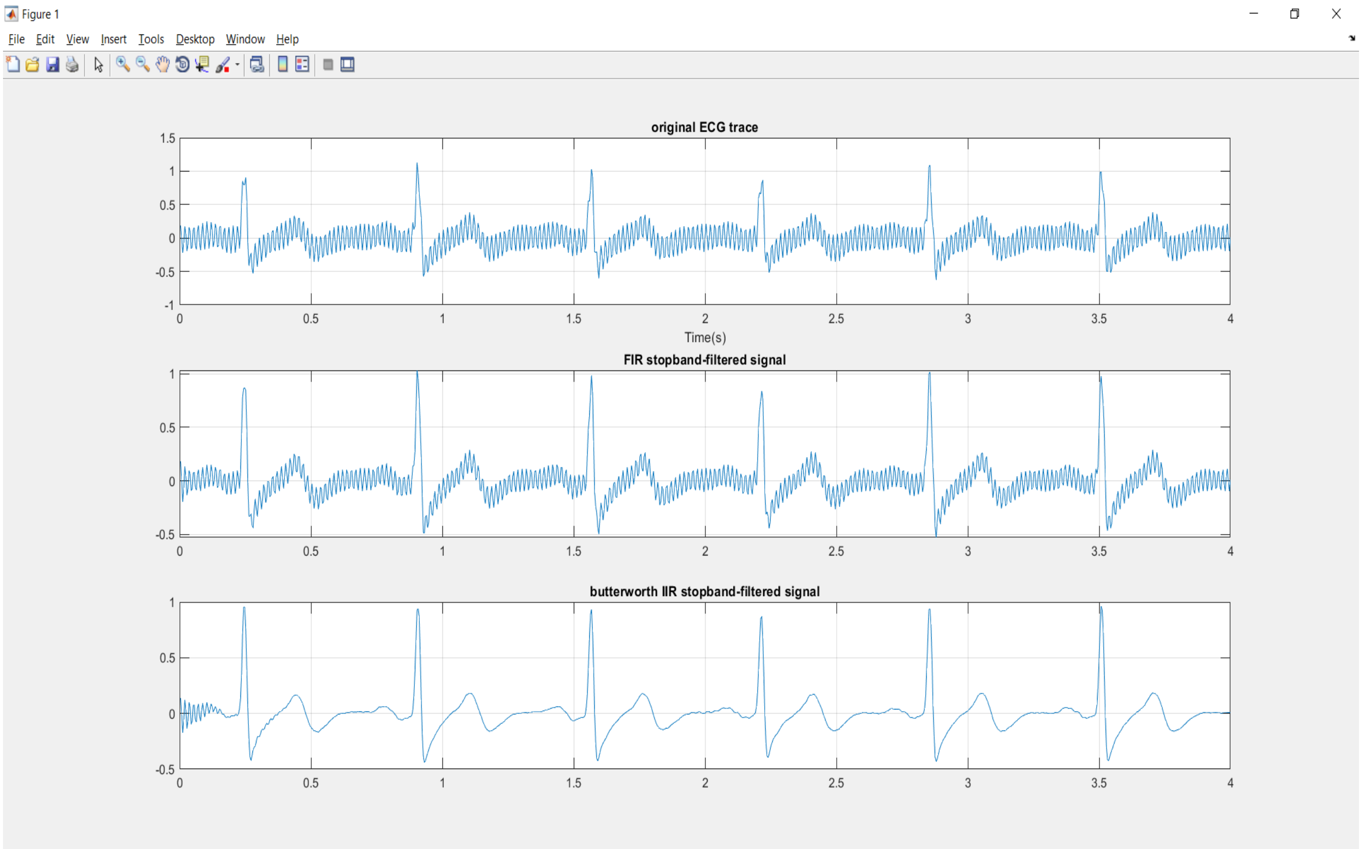

Figure 14. Applying FIR and IIR filters to an original ECG.

After the action of the two filters, it is clear from the graphs that the FIR has eliminated some of the signal noise while the IIR has removed almost all the noise.

Below I will mention about the two types of filters we used:

FIR:

FIR Filters have a finite impulse response. That is to say, that the impulse response only goes on for a set number of samples. It will never have more or fewer samples than that number of samples. The following picture is an example of the impulse response for a hypothetical FIR filter.

IIR:

IIR filters have an infinite impulse response. This means that the impulse response never becomes exactly 0 but rather approaches it. This is controlled via a feedback loop with a defined gain a (or feed-forward loop with defined gain b).

The main differences between the two filters are as follows:

- IIR is infinite and used for applications where linear characteristics are not of concern.
- FIR filters are Finite IR filters which are required for linear-phase characteristics.
- IIR is better for lower-order tapping, whereas the FIR filter is used for higher-order tapping.
- FIR filters are preferred over IIR because they are more stable, and feedback is not involved.
- IIR filters are recursive and used as an alternative, whereas FIR filters have become too long and cause problems in various applications.

By increasing the filter order of FIR I notice that it has a higher yield than before and similar to IIR as shown below:

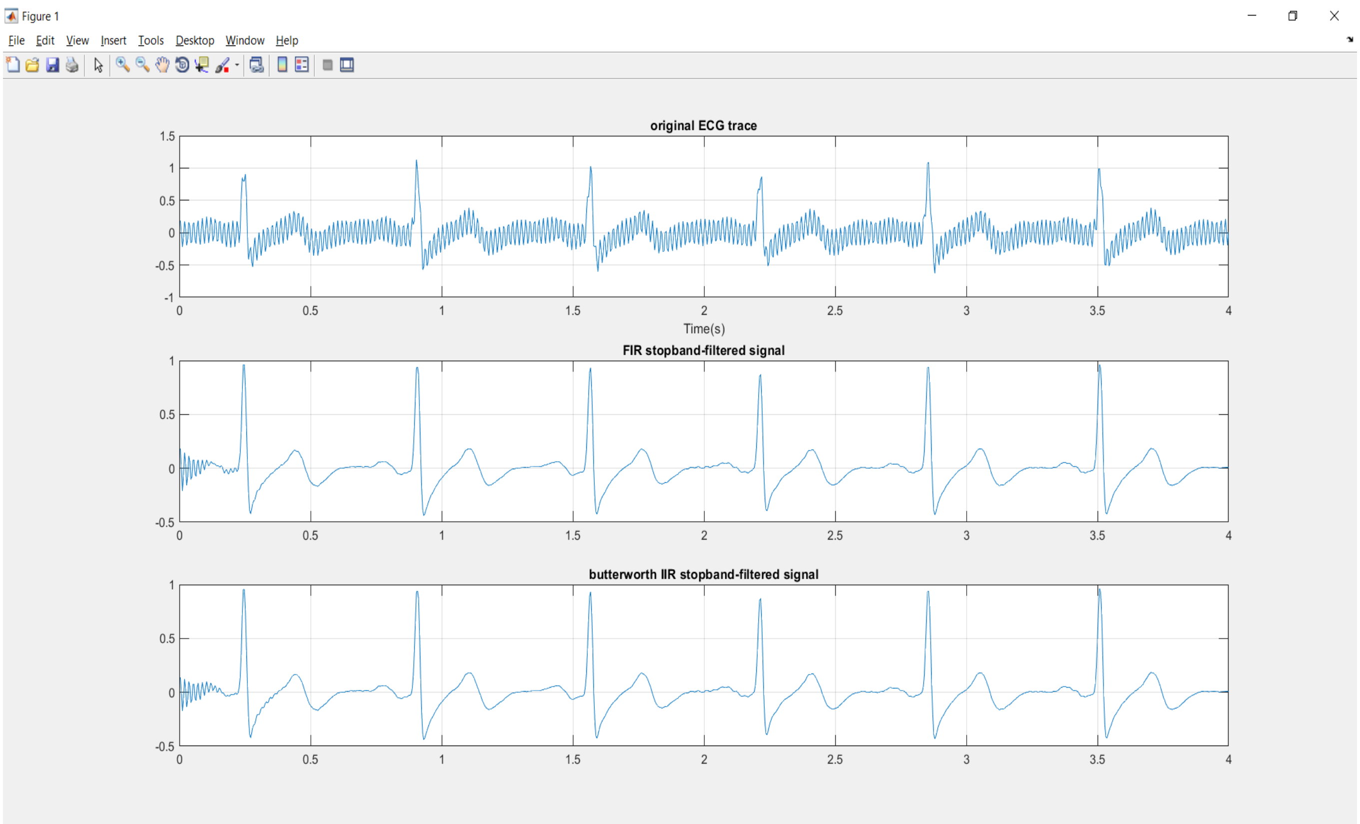

Figure 15. Applying FIR and IIR filters with a different order to an original ECG

Comparing the two filters with the commands fvtool(b,a) and freqz(b,a) we get the following 2 graphs:

As shown below the filter FIR only has magnitude:

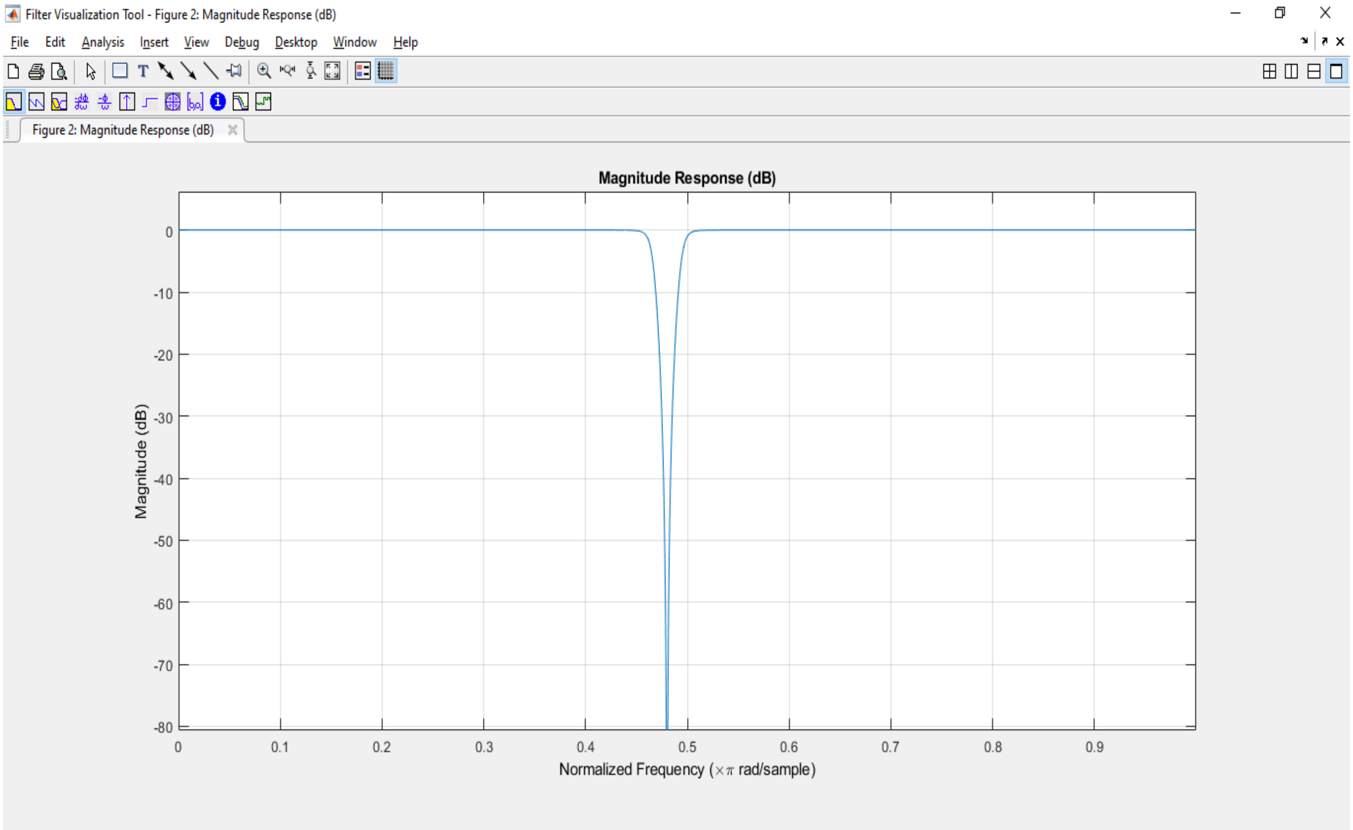

Figure 16. Illustrate the magnitude of the FIR filter.

On the contrary, the filter IIR has phase and magnitude as it seems below:

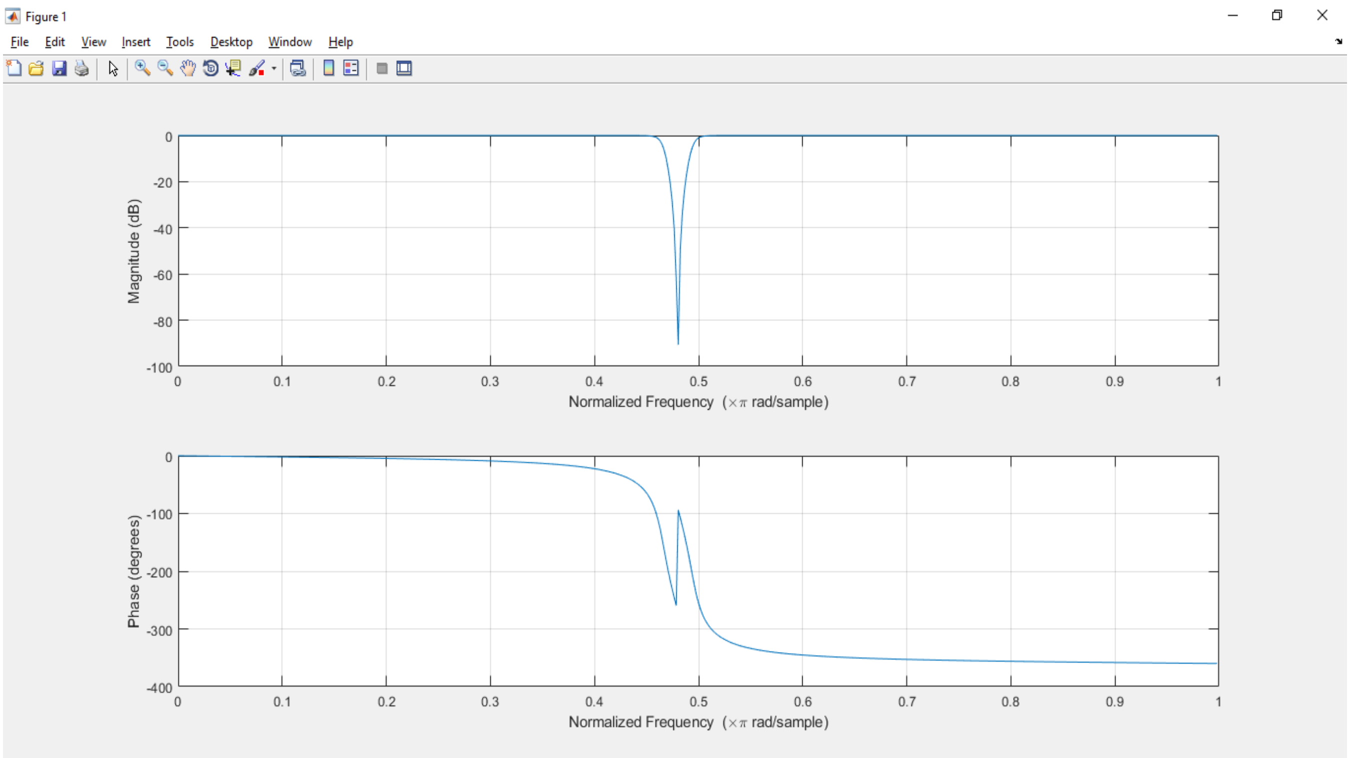

Figure 17. Illustrate the magnitude and phase of the IIR filter.

In conclusion, the most preferred filter is IIR as it is more efficient. Also, as we said before, by increasing the filter order of FIR approaches IIR efficiency.

5:

The last task that has been implemented is the following: load data, derive the unmixing-matrix with jader, estimating the ICs (source-signal), use the FAST ICA toolbox.

A:

In signal processing, independent component analysis (ICA) is a computational method for separating a multivariate signal into additive subcomponents. This is done by assuming that the subcomponents are non-Gaussian signals and that they are statistically independent of each other. ICA is a special case of blind source separation (Wikipedia).

B:

After executing the script for the last task we notice that the exported graphs contain signals from many different sources. Then, two different methods (JADE-ICA, FASTICA) are applied to separate the sources from which the signals in the first graph are derived.

Observing the results, we realize that the FASTICA method does not get the same results. In contrast, the JADER method always yields the same results. This is because the FastICA algorithm is executed M times in the data table X = [x1 x2. . . xN] consisting of N samples of k-dimensional vectors.

The results are not deterministic, as the wi initial vector of weights is generated at random in the iterations of fastICA. If ICA is run multiple times, one can measure the stability of a component. Stability of an independent component, in terms of varying the initial starts of the ICA algorithm, is a measure of internal compactness of a cluster of matched independent components produced in multiple ICA runs for the same dataset and with the same parameter set but with random initialization (Kairov et al. 2017)

After running the code twice, we got the following graphs:

First time:

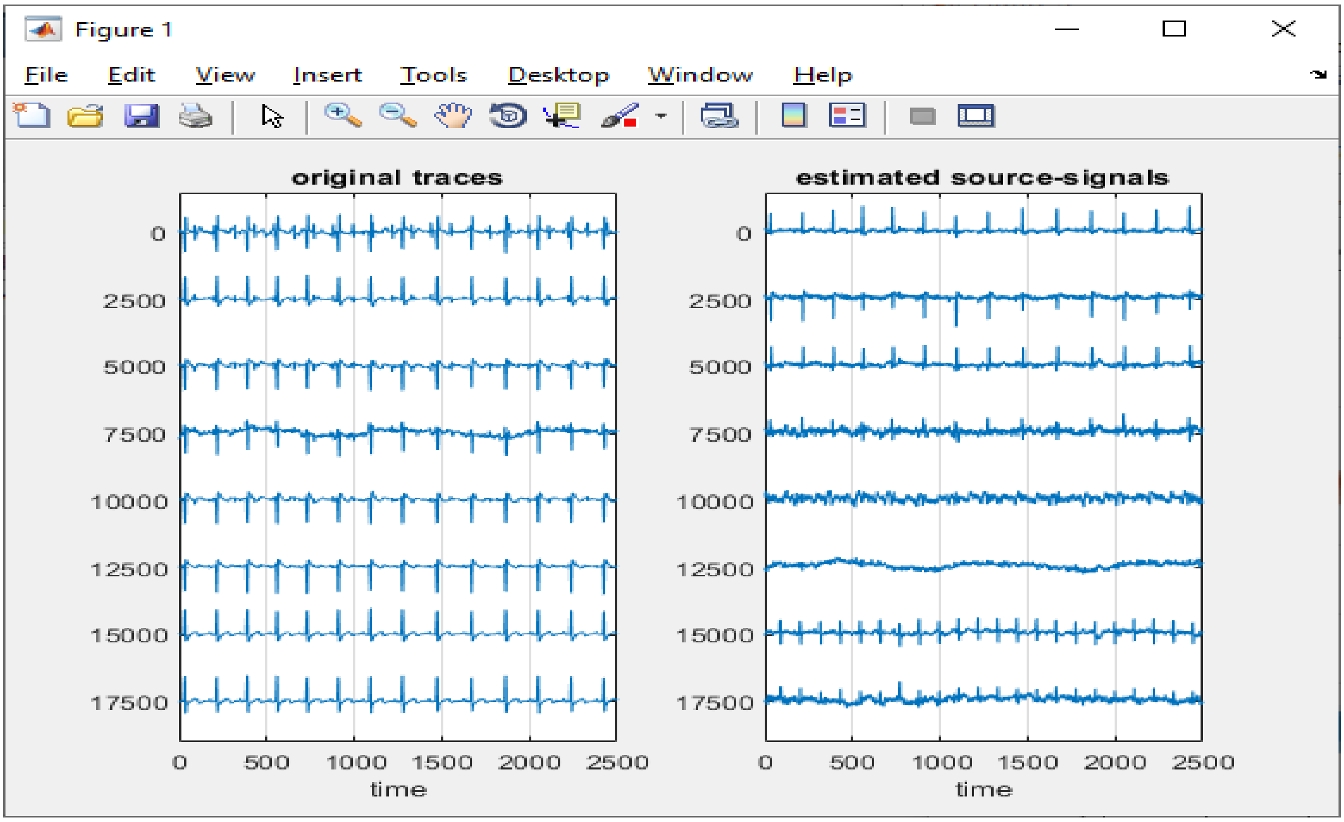

Figure 18. Depiction of original traces and sources-signals.

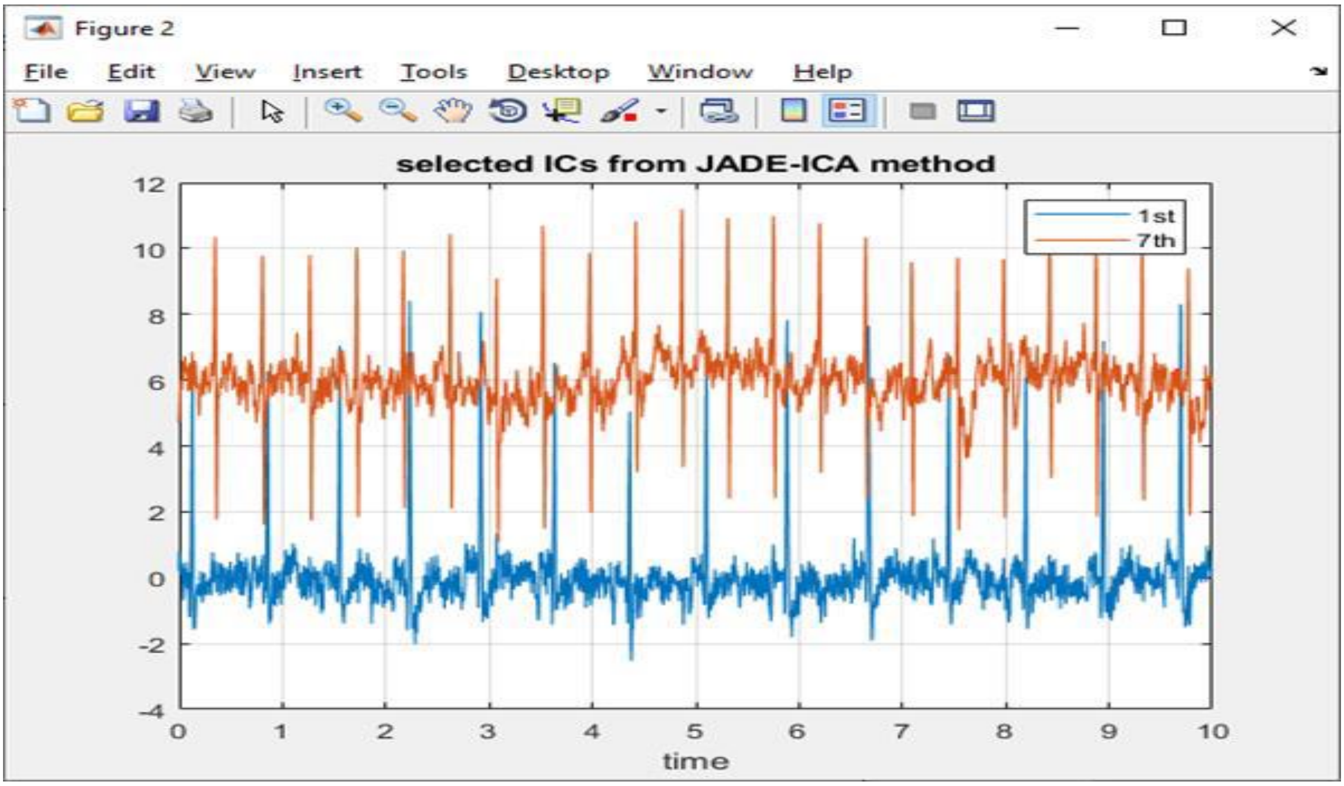

Figure 19. Illustration of the sources of the signals after action from JADE-ICA.

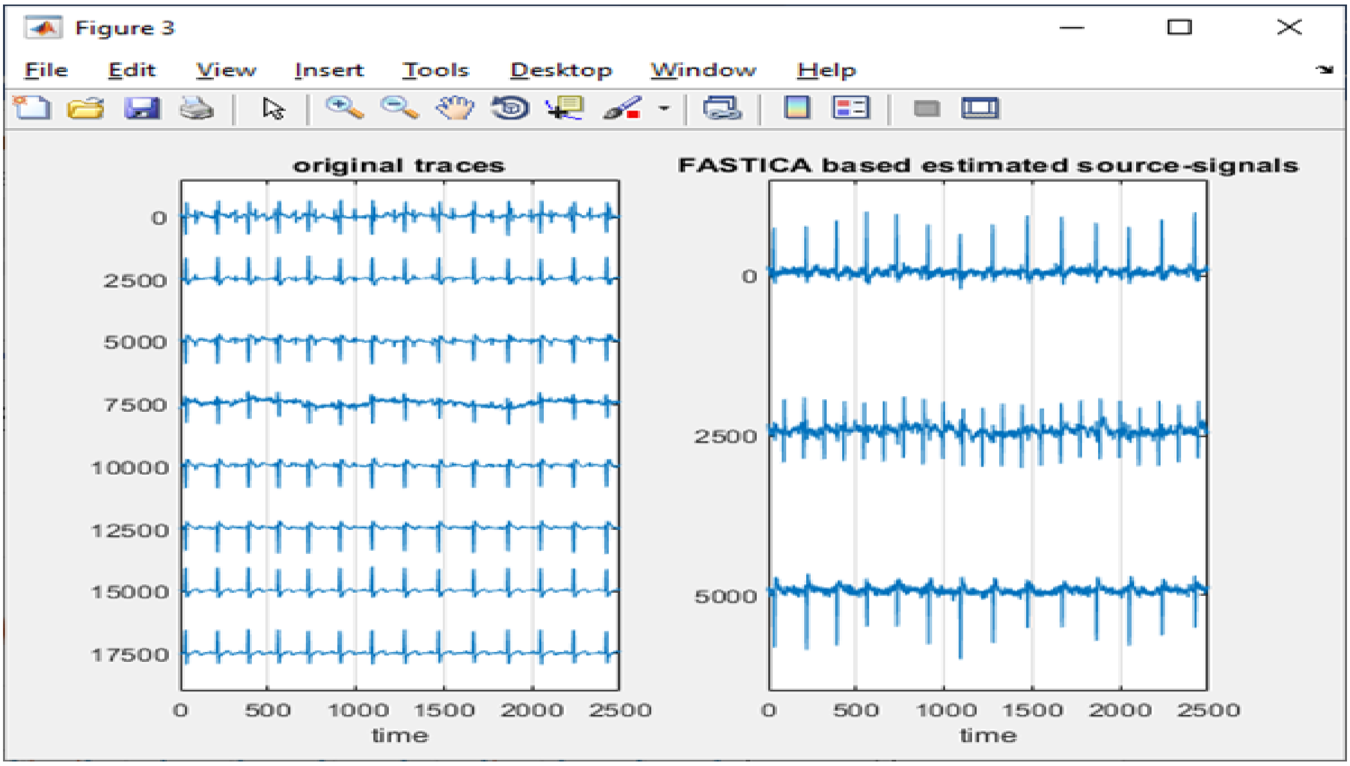

Figure 20. Illustration of the original traces and the sources of the signals after action from FASTICA.

Second time:

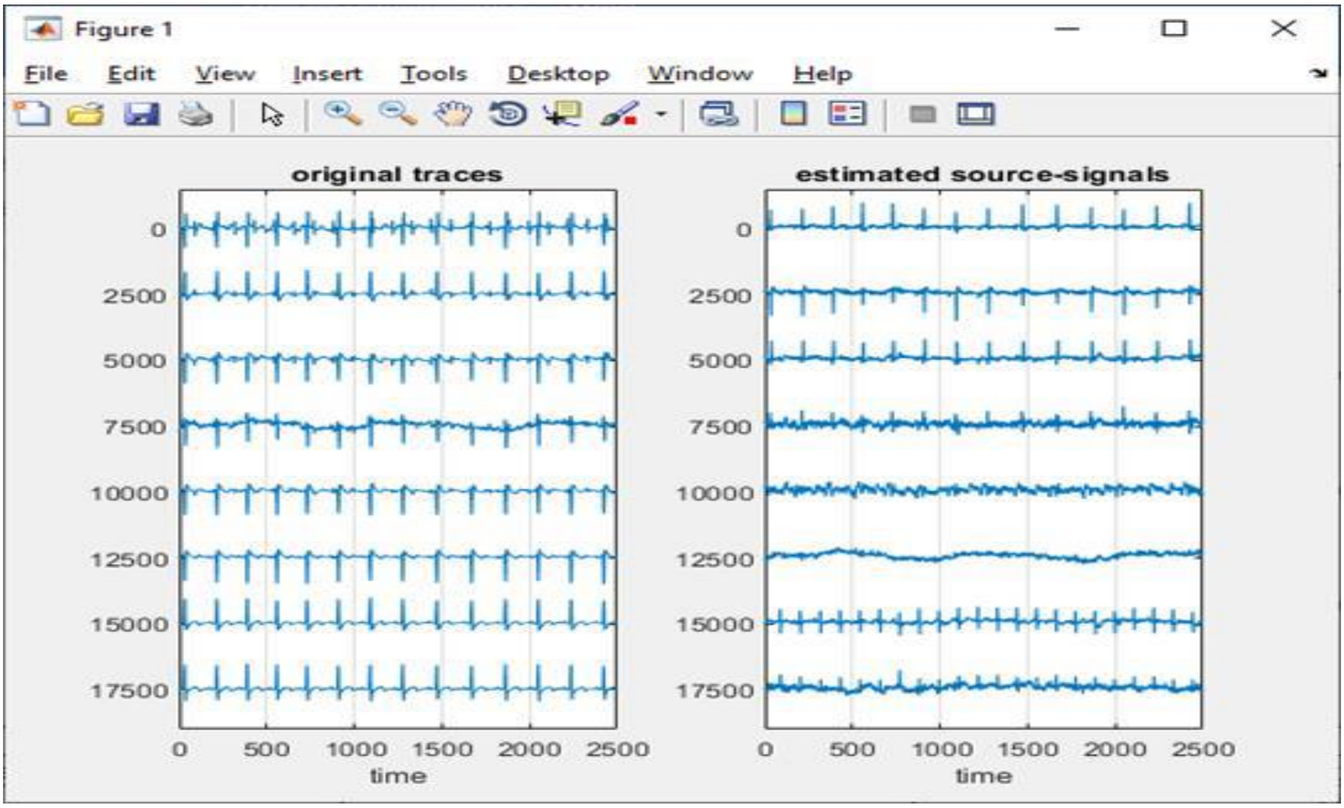

Figure 21. Depiction of original traces and sources-signals.

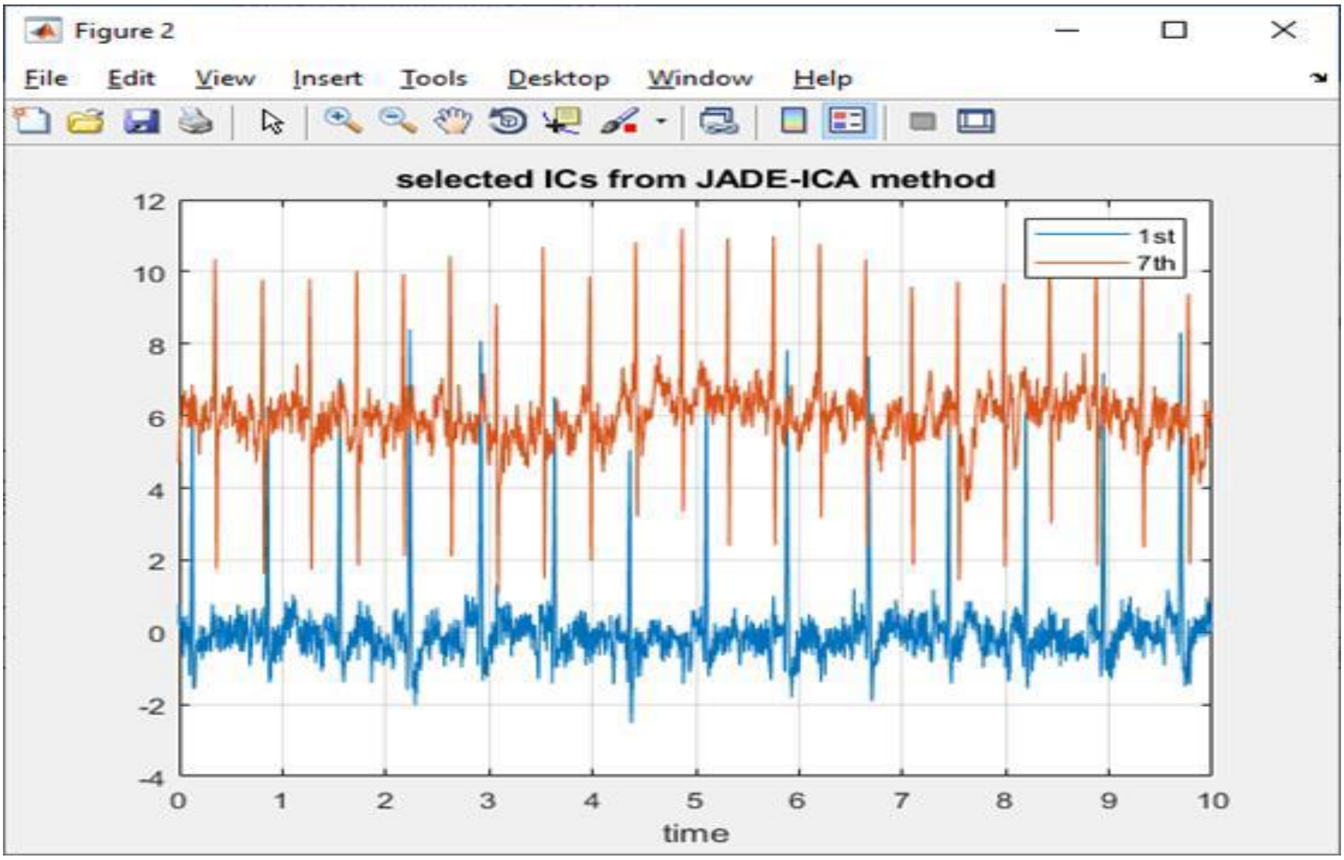

Figure 22. The same illustration of the sources of the signals after action from JADE-ICA.

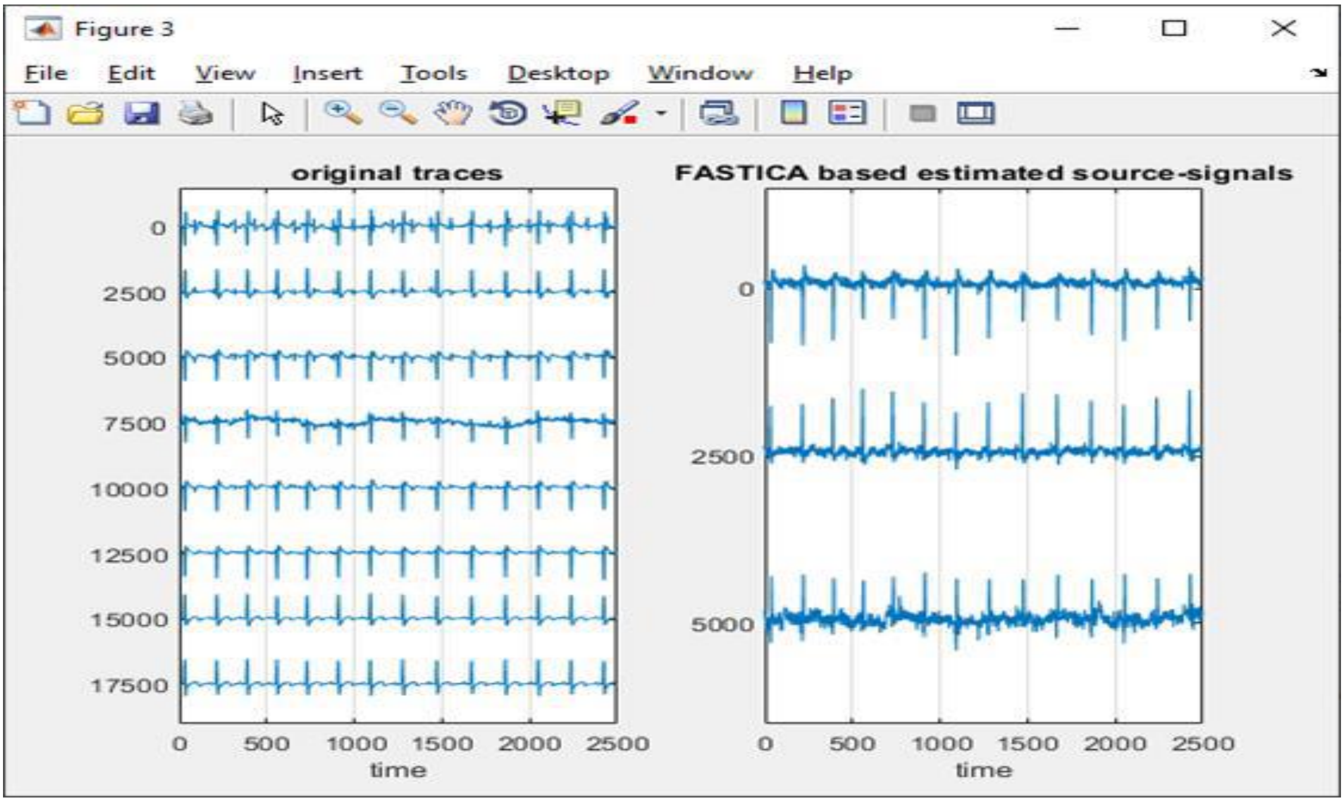

Figure 23. The different illustration of the original traces and the sources of the signals after action from FASTICA.

Realizes that when the FASTICA act, the results in the two graphs are different for the reason I mentioned earlier, while not the same as its action JADE-ICA.

C:

By reducing the sources, we receive half the graphs exported are the following:

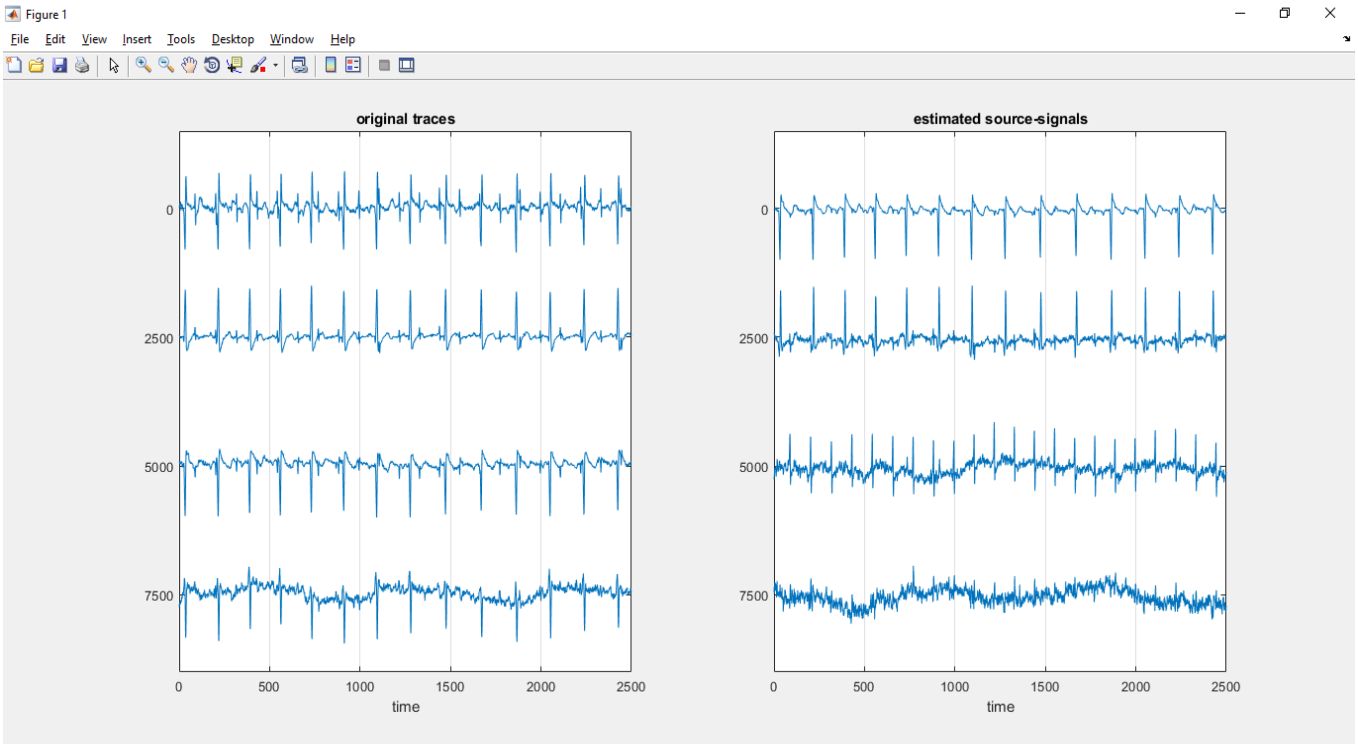

Figure 24. Depiction of original traces and the fewer sources-signals compare to before.

The following graphs are produced by JADE-ICA method:

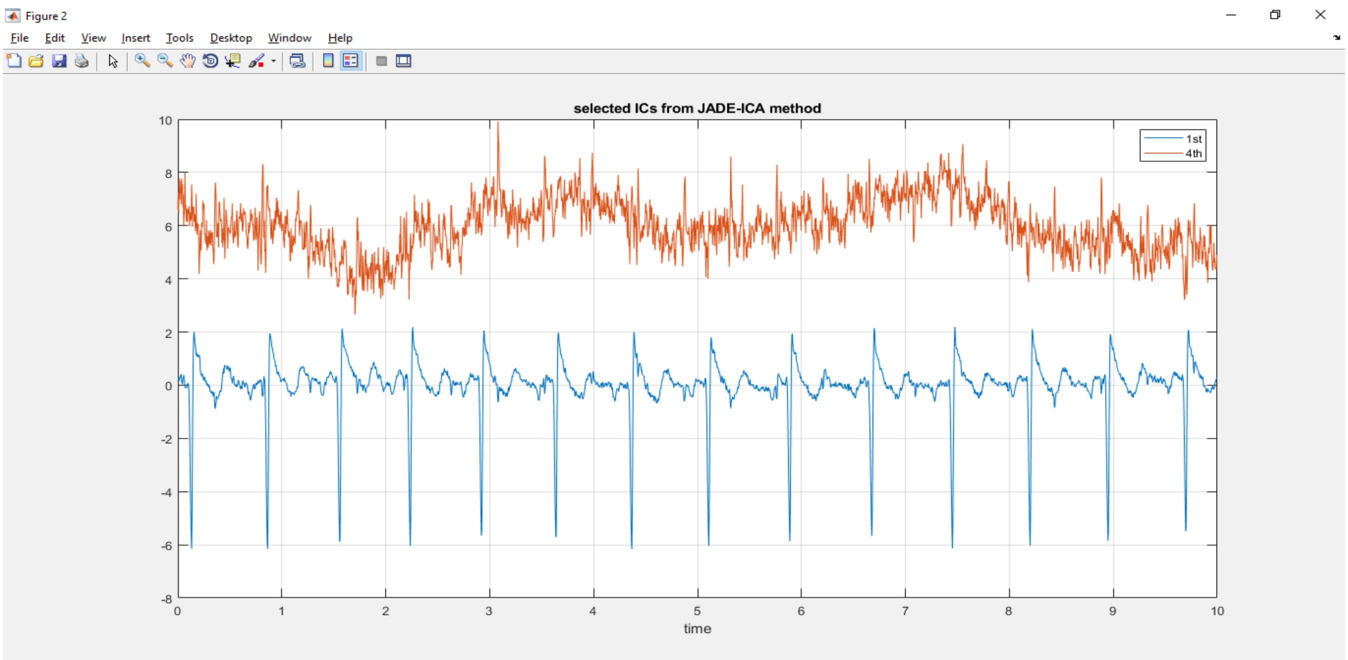

Figure 25. Illustration of the sources of the signals after action from JADE-ICA with fewer sources.

The sources after act FASTICA appear as shown below:

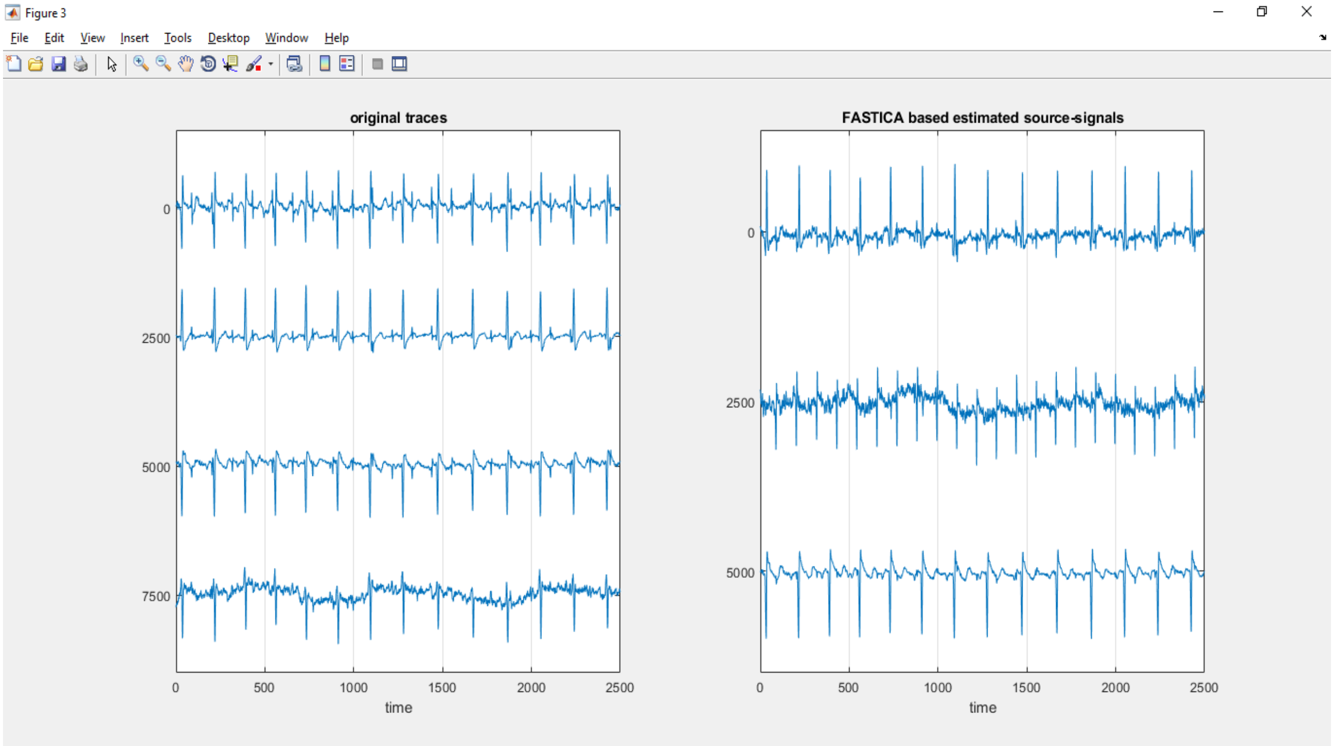

Figure 26. Illustration the original traces and the fewer sources of the signals after action from FASTICA.

We can see from the graphs that the noise has increased significantly as with fewer sources the output signal has more noise than before.