EKG Laboration

EEN070
Medicinteknik,
en Introduktion

Institutionen för Elektroteknik
Chalmers Tekniska Högskola

ECG Laboratory: LabPM

1 Summary

The goal of this laboratory experiment is to give an introduction to the acquisition and analysis of an ECG signal. You will measure the performance of an electrocardiogram and compare that with the theoretical predictions and simulations. Each group will be assigned a ECG circuit to measure your own ECG signal.

The experience is divided in an introduction to the circuit and the expected results from the circuit. Then the performance of the circuit is measured using a signal generator and an oscilloscope. The last step is measuring your own ECG signal and process the measured ECG. You will write a report summarizing your results and you need to answer the questions at the end of each section.

2 Introduction

2.1 The Electrocardiograph

In 1887 a British physiologist in London, Augustus Waller, published the first electrocardiogram using a capillary electrometer and electrodes places in the chest and back of a human. Previous studies had shown that electrical current could be measured from the heart beats of frogs but this was the first time done on a human. Waller demonstrated that electrical activity preceded ventricular contraction [1].

Dr. Willem Einthoven refined the capillary electrometer even further after getting inspired by the previous works conducted by Waller. In 1903 he successfully developed a new string galvanometer that he used in his electrocardiograph and weighted 272 Kg [3] (Figure 1).

The first electrodes (sensors) where buckets of electrolyte solution where the patient would insert their extremities. The positive leads were placed on the left arm and leg to produce positive deflections on the electrocardiogram as the heart electrical activation was noted to be from the right-upper quadrant to left-lower quadrant. In 1924, Einthoven was awarded the Nobel Prize in physiology and medicine for the invention of electrocardiograph.

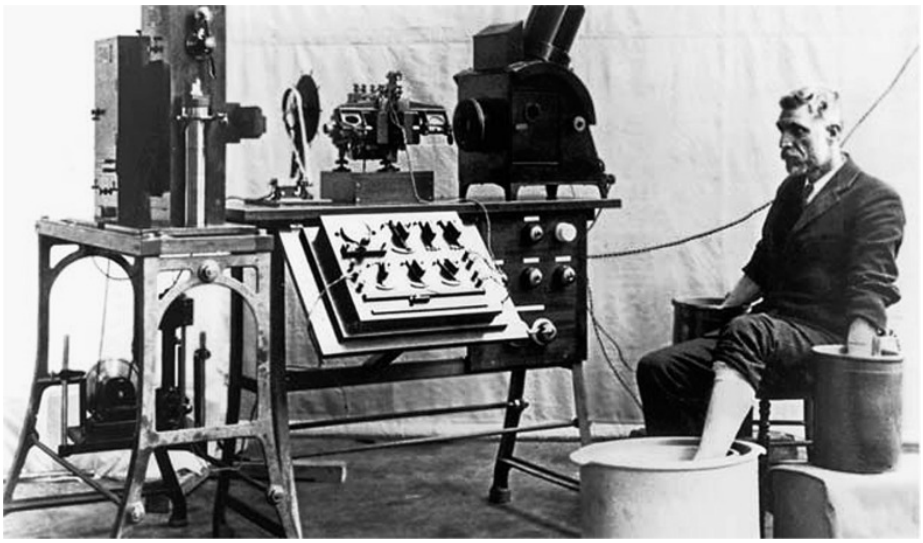

Figure 1: Old string galvanometer electrocardiograph showing the big machine with the patient rinsing his extremities in the cylindrical electrodes filled with electrolyte solution.[3]

In this electrocardiograph the signal drives a motor to print out the signal onto paper. Modern electrocardiographs use an analog to digital converter to convert the electrical activity of the heart into a signal. Since the signal is very small, like many other electrical biosignals, sophisticated data and acquisition techniques needs to be used before the analog to digital conversion. Practically, this is done by using an analog signal conditioner circuit that is composed from high-precision low-noise components.

2.2 The ECG Signal acquisition system

The process to acquire a general biosignal is shown in *Figure 2*. In this scheme, the signal is generated by a source (block A), in case of biosignals, the source is represented by the body itself. Typically, the signal is pre-processed by the analog signal conditioner (block B) before being analyzed and displayed. The most important pre-processing steps are amplification (the amplitude of the signal is increased) and filtering (unwanted signal components are suppressed).

In the next step, the signal is converted from analog to digital using an analog to digital converter, also called data acquisition system (block C). Practically, this means that the continuous analog waveform is transformed to digital sequences. The digital signal is then finally stored and displayed by electronic test instrument, for instance an oscilloscope, or a computer (block D). Before displaying, some signal processing can be done, for instance removing a noise by using digital filters (block E). Note that in some electronic measurement devices,

such as digital oscilloscope, the data acquisition system is directly embedded in the device.

In this lab, you will first study an analog signal conditioner circuit for ECG acquisition that you later use for measurement of your own ECG. Finally, you will apply signal processing techniques to extract an important information about your heart activity. The lab is divided into three parts: (1) **Preparation** in terms of Home assignments, (2) **Data acquisition** performed in the Lab and (3) **Signal processing** performed after the lab (using your computer).

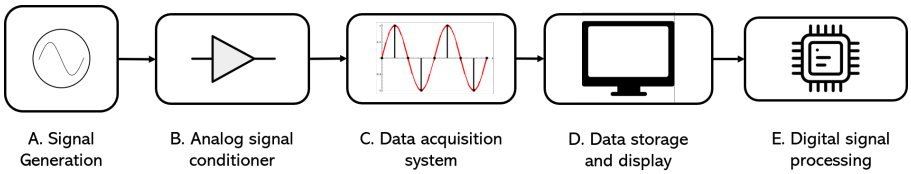

Figure 2: Signal acquisition process

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3 Home assignments before the lab

3.1 Study the ECG signal

1. Label the P wave, T wave and QRS complex, each segment and interval in *Figure 3* (fill the blank spaces).

2. How do signals in the ECG trace correlate with events in the heart (atrial depolarization, depolarization of ventricles, ventricular repolarization)?:

- P wave:
- QRS complex:
- T wave:

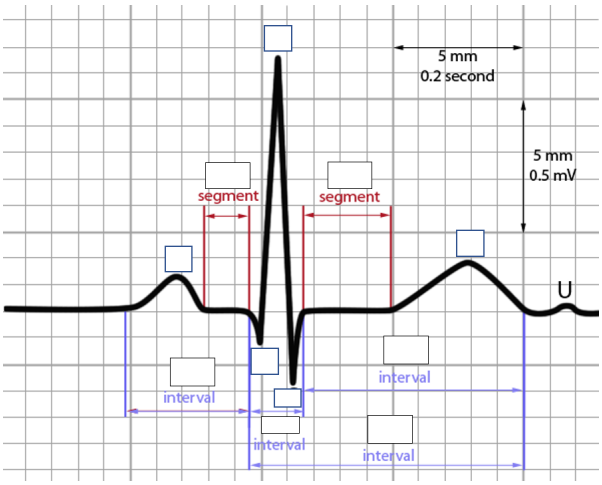

Figure 3: ECG signal

3.2 Study the Signal Conditioner Circuit

1. What is the amplitude or voltage of an ECG signal? Why do we need an amplifier?

2. What is the useful bandwidth of the ECG signal?

3. What are the values for the gain in each stage of the circuit shown in Figure 4? and the values for the cut off frequencies of the filters? You may use the formulas given in section 1 of Part 1.

ECG Lab
Part 1: Introduction to the circuit, testing and ECG acquisition

The electrocardiograph is essentially an electronic device that amplifies the very small potentials present at the surface of the body, so that they can be displayed on a video screen or recorded permanently on paper. The signal is picked up by electrodes placed at certain well-defined anatomical positions on the body surface. The heart of the of the ECG is an electronic amplifier with two input terminals, a non-inverting input terminal (+) and an inverting input terminal (-). However, signal conditioner circuit must comprise of other components important for pre-processing of the acquired signals.

In this first part of the Lab, the signal conditioner circuit used for the ECG measurement will be simulated and tested, You will compare the results of the second (Gain) stage with the results obtained from the simulations. Finally, you will use the circuit to acquire your ECG signal under various conditions.

1 The Signal Conditioner Circuit

This section will give an introduction to the ECG circuit that you will use for measurement. The topology of the ECG amplifier is shown in Figure 4. The circuit is divided in three stages:

- Instrumentation amplifier & low pass filter: the instrumentation amplifier is realized by combining the three operational amplifiers A1, A2 and A3 in the typical instrumentation amplifier configuration (see Figure 5). The low pass filter is obtained by adding the capacitance C4. The filter quality is further improved by adding the bypass capacitors C2 and C3, which reduce the tendency of the respective operational amplifiers to amplify high-frequency noise
- Additional gain stage & band pass filter: the gain is assured by the OpAmp A4, while the filter is realized thanks the connection in series and in parallel of resistors and amplifiers (R11, R12, R13 and C5, C6)

- Isolation amplifier

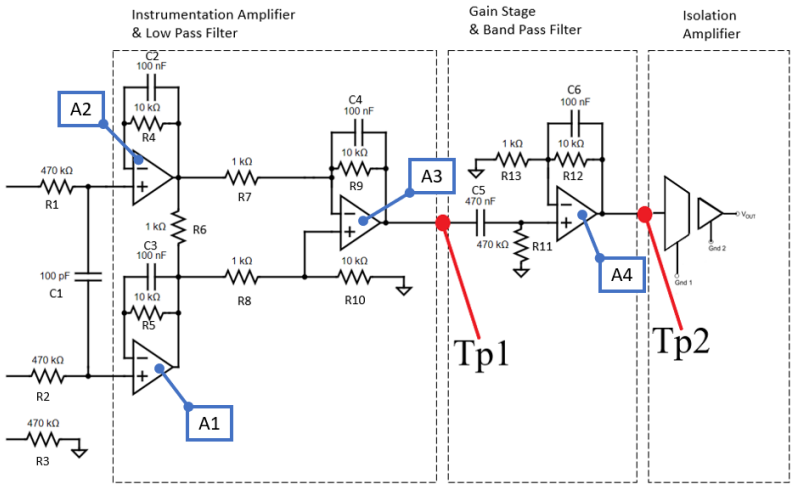

Figure 4: Schematic of ECG amplifier circuit

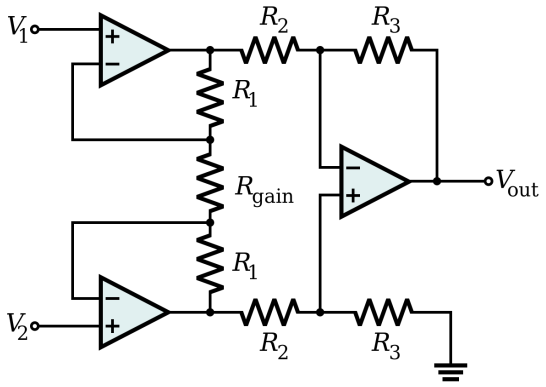

Figure 5: Typical configuration for an instrumentation amplifier

Before the amplifier there is a pre-filter stage, represented by the capacitor C1, which will remove any RF noise from entering the op-amps. The input impedances must be the same value and the cutoff frequency is set to a value much higher than the low pass filter in the instrumentation amplifier. The important parameters can be calculated from the following formulas: The gain

in the instrumentation amplifier is given by

$$G1 = 1 + 2 * \frac{R4}{R6} * \frac{R9}{R7} \tag{1}$$

and the cut off frequency is given by

$$f_{c1} = \frac{1}{2 * \pi * C4 * R9} \tag{2}$$

In the additional gain stage and band pass filter, the gain is given by

$$G2 = \frac{R12}{R13} \tag{3}$$

The high pass filter cut off frequency

$$f_{ch} = \frac{1}{2 * \pi * C5 * R11} \tag{4}$$

and the low pass filter cut off frequency

$$f_{cl} = \frac{1}{2 * \pi * C6 * R12} \tag{5}$$

2 The simulated performance of the circuit

To verify that performance of the circuit match the design criteria in terms of the gain and cut-off frequencies various simulators can be used. To this purpose we have used an analog electronic circuit simulator LTSpice to simulate the Signal conditioner circuit. Note, that the isolation amplifier was excluded from the model. The simulation results, i.e., the gain and cut off frequency for the instrumentation amplifier are shown in Figure 6. The output from the second gain stage and band pass filter is shown in Figure 7. To make the readouts easier, we put cursors at the 3dB point in both figures.

2.1 Tasks related to Simulation part

1. Determine the simulated gain and the cut-off frequency for both stages of the circuit as provided in Figures 6 and 7.

2. Compare the calculated and the simulated gains for the first stage of the circuit. Are they similar? Make the comparison between the cutoff frequencies?

3. Determine the Gain of the second stage. Is it the same as the calculated one? Determine the cut-off frequencies for the band pass filter?

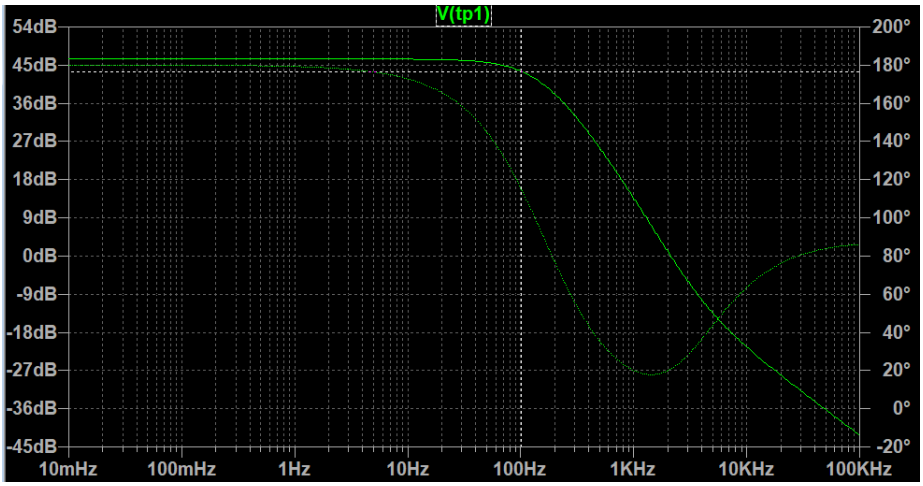

Figure 6: Output from instrumentation amplifier and low pass filter

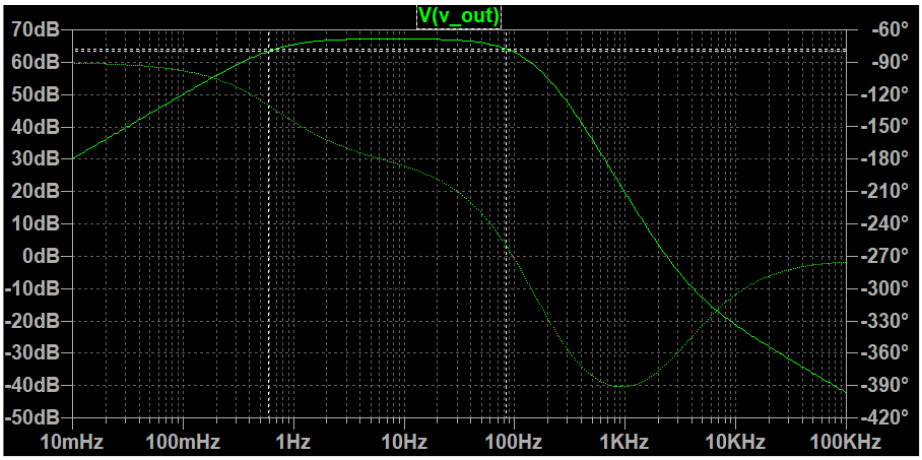

Figure 7: Output from second gain stage and band pass filter.

3 Testing The Circuit

For oscilloscope and function generation, you will use the NI ElVIS platform. The measurement setup is shown in Figure 8. The explanation of how the connections shall be done is stated bellow. Further, we recommend you to use an instruction video *ECG Connections.mp4* available at Canvas.

OBS. Be careful with connections. For a proper functioning of the board as a interface between the PC and LABVIEW, you need to use the correct connections.

The following connections are needed (see Figure 8):

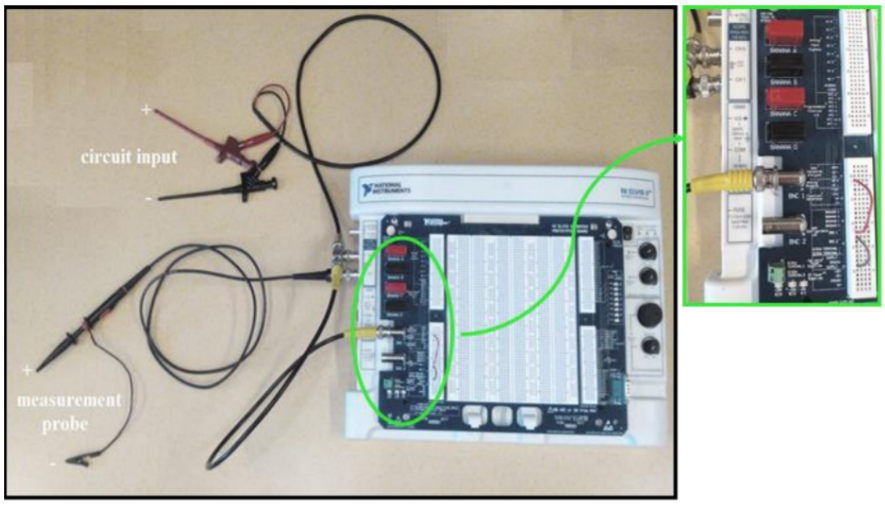

Figure 8: Measurement set up using the NIElvis platform.

- Connect USB cable between NI Elvis and PC.
- Connect Power supply to NI Elvis platform socket.
- Use a T connector for the BNC cables in CH0 (NI Elvis platform). Connect BNC1 with one of the outputs of CH0. Connect the other output of CH0 to a BNC cable with two separate endings, one for ground (black) and one from signal (red).
  You will use this ending to send the signal to the ECG Circuit.
- Connect BNC1+ with the analog output AO0 in the NI Elvis platform using jumper breadbording cables.
- BNC1- to ground using jumper breadbording cable.
- Connect a probe to CH1. You can use this probe to measure the output of your ECG circuit.

3.1 Software Settings

To run the NIElvis platform go to *Start→ All programs → National Instruments → NIELVISmx for NIELVIS & NI my DAQ* and choose *NIELVISmx instrument launcher*.

You will use the oscilloscope to measure and display the signals from the circuit. The oscilloscope coupling should be in DC mode when measuring to be able to detect a DC offsets if present.

- To generate a signal, select the function generator in the ECG folder(C:\ECG:\new FGen). Choose the device. The signal you will generate should be a Sine wave with frequency 30Hz an amplitude 100mvpp.
- Click on update and then run to start the function generator. Any time you want to change any of the configurations in New FGen, press the update button.
- Select the scope instrument in the oscilloscope. Choose the channel to measure the input as scope CH0 and make sure that the channel is enabled.
- Click run to start the oscilloscope and press Autoscale to see the signal. you can change the timebase and scale manually. Adjust them until you see your input signal.
- If you want to measure the output signal as well, add another channel to the scope. Enable channel 1 and adjust Timebase and scale until a clear signal is diplayed. Choose the output as scope CH1.

3.2 Measurement tasks

The circuit has some test points that you can use to measure the output from each (amplification) stage, as shown in *Figure 9*. You will use these test points to measure the gain and frequency response. In Tp1 you can measure the output from instrumentation amplifier and low pass filter, while in Tp2 you can measure the output from the second gain stage and the band pass filter as shown in *Figure 4*.

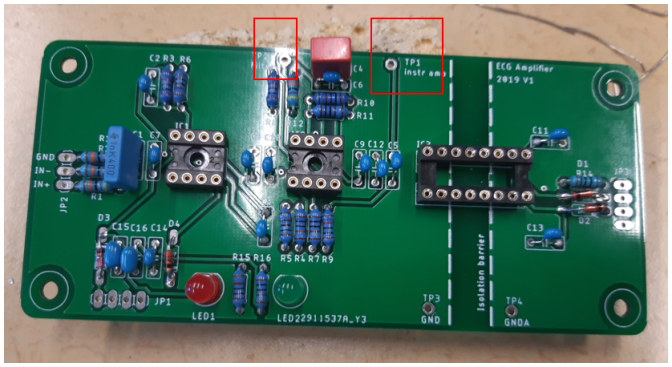

Figure 9: Circuit and test points

Note: In order to measure the gain and cut off frequencies, we need to connect the circuit in differential mode, as shown in *Figure 10*.

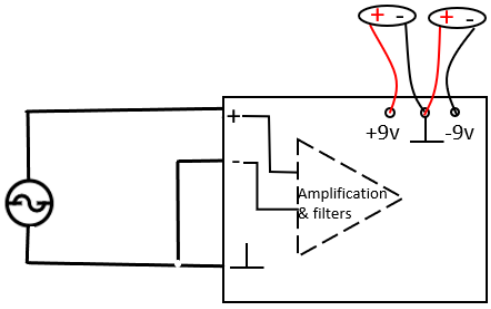

Figure 10: Input configurations for testing differential mode amplification of the circuit

1. Measure the differential gain at 30 Hz for all stages (i.e. both in Tp1 and Tp2). Fill Table 1 with your measurements.

   Note: The gain is calculated by dividing the output voltage by the input voltage as shown in equation 6 (the voltage used can be either peak to peak or rms, the ratio should be the same).

$$G = \frac{V_o}{V_i} \tag{6}$$

	Measured
Tp1	
Tp2	

Table 1: Measurements of Tp1 and Tp2 using 30 Hz.

2. Measure the gain with respect to the frequency at Tp2.

   The frequency band for the measurements is 0.5 Hz to 400 Hz. You may decide which frequency points you want to measure within this interval. Start by changing the frequency to 0.5 Hz and measure your gain, decide on your next frequency point (for example 20 Hz) and measure your gain. You can use this information to fill table 2.

   Note: The frequency points given in Table 2 are just an example. You may use them or you may decide to use different ones.

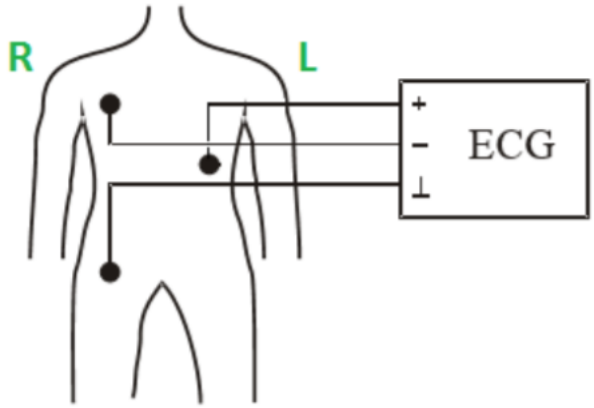

Figure 11: Electrode set up for measuring your own ECG.

Frequency [Hz]	Input [V]	Output [V]	Gain
0.5			
20			
50			
80			
100			
200			
300			
400			

Table 2: Measurement of gain in Tp2 with respect to frequency.

3. Verify a proper functioning of the isolation amplifier

   Now you will include the isolation amplifier to the measurements. First, you need to verify that the component is not damaged and it does not (considerably) change the output of the system. For the verification, use an input signal of 30 Hz.

4. Measure your own ECG

   Attach the electrodes to the body. Follow *Figure 11* for the lead positions. Ensure an effective contact between electrode and skin.

   To measure and display the signal you will need to connect the output to the computer using an A/D card and use the prepared labview program in C:/ECG/ECGMon.exe.

Questions

(a) Inspect the ECG signal. Identify the P-wave, the QRS-complex, and the T-wave.
In the chart program, experiment with different settings for the time scale and the voltage scale so that, e.g. the waveform is not too big or small in amplitude.

(b) Identify Waves and Intervals
Set the time scale to an appropriate value for displaying the overall shape of the P-QRS-T waveform. Examine the RR, PR, QRS and QT intervals. Compare to the normal ranges given in the table 2 (in seconds).

(c) Try moving your arms while you measure. Does this affect the ECG signal?

(d) Plot the measured gain vs the frequency. Comment on your findings.

Interval	Min	Max
RR	0.6	1.2
PR	0.12	0.20
QRS		0.1
QT		0.42

Table 3: The normal ranges of the RR, PR, QRS and QT intervals.

Do not forget to save the measured ECG signal for the next section.

ECG Lab
Part 2: Signal Processing with Matlab

In the second part of this laboratory, the signal you previously acquired will be digitally processed, in order to remove the noise and the artifacts affecting it. Then, the QRS complex will be identified using the Pan-Tompkins algorithm.

4 ECG Signal Processing

The biological signals are in general weak and can therefore be hidden in noise and artefacts accompyning the measurements. In particular, the ECG signal contains, besides the clinical data, noise content that is related to 50-60 Hz noise coming from the power line interference, electromyography (EMG) signal from muscle activity, and motion artifact from the electrode and skin interface.

Removing and quantifying the noise information in the ECG is not easy and sometimes not completely possible. This happens because there are many different types of interference and artifacts that can take place at the same time. Further, the noise is often unpredictable and it is not clear when it starts and how long it lasts. In general ECG signal noise can be classified as:

- **Power line interference:** 50-60 Hz noise
- **Electrode contact noise:** loss of contact between the skin and the electrode. This type of noise normally is a sharp change in the signal.
- **Motion artifacts:** movement of the electrodes away from the contact area on the skin, this leads to changes in the impedance between the electrode and skin. This impedance change causes a potential change in the ECG signal. This potential change normally looks like a baseline change .
- **EMG noise:** electrical activity due to muscle contractions. The spectral content of this noise is expected to be in the range 0 to 10000 Hz.
- **Baseline drift:** this noise normally occur due to respiration activity in the frequency range 0.15 and 0.3 Hz.

4.1 Power Line Interference

Several techniques have been developed to remove this type of interference like band stop FIR and IIR filters, adaptive filters, subtraction of estimated components and wavelet transform.

You will design a second order IIR notch filter using the function `iirnotch` in MATLAB.

```
wo = F0/Fn;
bw = wo/35;
[b,a] = iirnotch(wo,bw);
```

Where F0 is the notch frequency and Fn is the nyquist frequency (Fs/2). You can check the filter performance using `freqz`.

```
figure
freqz(b,a,2^16,Fs)
Filtered_signal= filtfilt(b,a,signal);
```

Questions

1. Use the Fourier transform to find the frequency components of the ECG signal before filtering. Can you see the power line interference? which F0 should you use?

2. Filter the signal and plot the frequency components again. Did your filter work?

Make sure to include the frequency response of your filter as well as the other plots in your report.

4.2 Baseline Drift

The frequency content of a baseline drift is usually in the frequency range of 0 to 0.5 Hz. The two major techniques for baseline removal are lineal filtering and polynomial fitting. You will design an IIR Chebyshev Type II band pass filter.

```
Wp = [1   100]/Fn;     % Normalised Passband
Ws = [0.5  120]/Fn;    % Normalised Stopband
Rp =   1;              % Passband Ripple (dB)
Rs =  50;              % Stopband Ripple (dB)
```

The steps you need to follow to design the Chebyshev type II filter are the following (feel free to experiment with other types of filter as well, the steps are very similar):

1. To determine the order, start with the cheb2ord function.

2. Use the output of cheb2ord to design a transfer function [z,p,k] realization of your filter with the cheby2 function.

3. Use the zp2sos function to create a second-order-section representation for stability.

4. Use the freqz function (be sure to give it your sampling frequency, 'Fs', to make the output understandable) in order to check the filter performance to be sure it is stable and does what you intend it to do.

5. Use the filtfilt function for the actual filtering (filter will introduce a phase distorion).

Look at the frequency components of your signal before and after using your filter. Did the filter work like it should?. Take a look at your filtered ECG signal, Does it look different? were you able to remove the baseline drift?

Questions

1. Look at the frequency components of your signal before and after using your filter. Did the filter work like it should?

2. Take a look at your filtered ECG signal, Does it look different? were you able to remove the baseline drift? comment on your findings.

Make sure to include the frequency response of your filter as well as the other plots in your report.

4.3 Muscle Noise Filtering

Electromyographic noise (EMG) refers to the electrical activity that happens because of muscle contraction. Its spectral content cover bewteen DC and 10 000 Hz. This represents a more difficult challenge since the spectral content of muscle activity overlaps with the spectral content of the ECG signal. Beat averaging and median filtering are widely used estimators in determining the dominant beat morphology. Successful noise reduction by ensemble averaging is restricted to one particular QRS morphology at a time, and requires that several beats be available. which is a limitation to this technique.

An alternative technique for attenuation of muscle noise and other types of ECG noise is the empirical mode decomposition (EMD) [2]. The aim of EMD is to decompose the original signal into a sum of intrinsic mode functions (IMFs), where an IMF is defined as a function with equal number of extrema and zero crossings with its envelopes.

The EMD of the original signal is

$$x[n] = \sum_{k=1}^{N} c_k[n] + r_N[n] \tag{7}$$

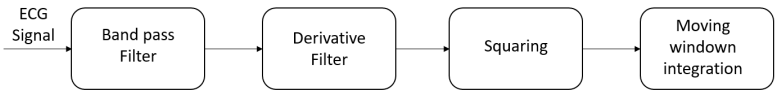

Figure 12: Pan-Tompkins pre-processing

Where $c_k[n]$ are the IMFs and $r_N[n]$ is the residual. The result of EMD produces N IMFs and a residue signal, which is in general a monotonic slope. We will verify that lower-order IMFs capture fast oscillation modes and higher-order IMFs typically represent slow oscillation modes.

You will filter the noise by doing a partial reconstruction using only certain IMFs.

```
[imf,residual] = emd(signal)  % EMD
```

First show that the using equation 7 you get the original signal. Plot the IMFs by using the function `emd(signal)` without output arguments. Now try doing the reconstruction not using all of the IMFs. You can choose which IMFs to use for the reconstruction depending on which frequency components you want to keep on your signal. Does the reconstructed signal present less noise?.

Questions

1. Look at the IMfs of your ECG signal. Which correspond to higher frequencies and which to lower frequencies?

2. Experiment with the reconstruction. Use different IMFs to see if you can take away noise. When you are happy with the final result you can stop. Which IMFs did you use for the reconstruction?

3. Plot your reconstructed ECG signal, does it present less noise?

Make sure to include the IMFs as well as the other plots in your report.

4.4 QRS Detection

The Pan-Tompkins Algorithm [4]. Figure 12 shows the prepossessing step used for the ECG signal.

First a band-passfilter is used with bandwidth of 5-15 Hz, to reduce noise and P wave /T wave frequency content. Additionally this will maximise the contribution of the QRS complex. The next step is a derivative filter, which provides information about the slope of the QRS. The filtered signal is squared, this will enhance dominant peaks and reduce the possibility of confusing a T wave as an R peak. A moving average filter is used to provide information

about the duration of the QRS complex. After the pre-processing steps adaptive thresholds are applied to detect the peaks of the filtered signal.

You will use the code [5] given to you to perform this pre-processing and decision rules. You can use the signal given to you without filtering since the algorithm also has filters. You can use the function the following way:

```
[qrs_amp_raw,qrs_i_raw,delay]=pan_tompkin(ECG,fs,1);
```

Questions

1. Explain in your words what you think is happening at the output of every step of the process. For example: What do you see after the bandpass filter and after the derivative?

5 Conclusion

Congratulations, you have finished the practical part of the lab. Your experience has to be now summarized and presented in a written form. The report does not need to include theory part, but a complete description of the measurement results and signal processing results with graphs and comments for each task. Make sure to answer the questions in each section of the labPM. The report can be written in a group.

Thank you for participating!

References

[1] S Serge Barold. Willem einthoven and the birth of clinical electrocardiography a hundred years ago. *Cardiac electrophysiology review*, 7(1), 2003.

[2] Madeiro Joao Paulo do Vale, Cortez Paulo cesar, Jose Maria da Silva Monteiro Filho, and Angelo Roncalli Alencar Brayner. *Developments and applications for ECG signal processing: modeling, segmentation, and pattern recognition*. Elsevier/Academic Press, 2019.

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[4] Jiapu Pan and Willis J. Tompkins. A real-time qrs detection algorithm. *IEEE Transactions on Biomedical Engineering*, BME-32(3):230–236, 1985.

[5] Hooman Sedghamiz. Matlab implementation of pan tompkins ecg qrs detector.