

Electricity from the Heart

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Electrocardiography is the clinical term assigned to the process to producing a electrocardiogram (ECG or EKG), a recording of heart's electrical activity. The ECG is a primary and generally the forerunner method for diagnosing heart disease, as it permits the ability to detect electrical and mechanical defects of the heart.

Given its use, understanding the ECG can become a valuable skill. There are three methods popular in clinical electrocardiography [1]. First is the standard clinical ECG which consists of twelve leads placed on the patients body. Second is the vector-cardiogram (VCG) which contains three orthogonal leads which output a graphical view of the excitation of the heart. The last method corresponds to monitory ECG, also referred to as arrhythmia analysis is used for monitoring heart rhythm in life threatening situations using either one or two leads.

The VCG takes a set of three body potentials from three electrodes as its input to design a three dimensional vector model of cardiac excitation [1]. The electrodes are conductive pads attached to the body surface with conductive gel to reduce potential impedance. With a pair of electrodes, we can use one as a reference terminal so the pair on a whole acts as a lead providing the electrical potential difference between the electrodes.

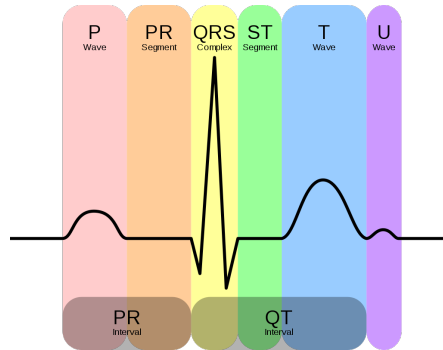


Figure 1: Typical representation of a normal ECG [2].

A healthy ECG signal has a standard template, shown in Fig. 1. The main components are the P wave, the QRS complex and the T wave. The complete wave represents an orderly progress

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of depolarization which starts from the pacemaker and moves through the atrium and ventricular walls before returning to the sinoatrial node. The P wave represents atrial depolarization, the QRS complex represents ventricular depolarization, the T wave represents ventricular repolarization and finally the U wave represents the papillary muscle re-polarization. For further understanding look at the by Dr. Sabieh (a co-author) explaining the process of ECG (https://www.youtube.com/watch?v=o9CA-gk5y5U&ab_channel=khwarizmisciencesoc).

In the current experiment, we will be using an ECG circuit, a V-Probe and Physlogger to record a sample ECG. The signal will then be digitally filtered using a Python code before we can process it further. Our goals include, obtaining the power spectrum of the signal, the identification of the QRS to study RR intervals and the corresponding heart rate. In a dummy model, the ECG signal courses out of an electric dipole vector formed at the heart in progressive phases of depolarization and repolarization.

KEYWORDS

ECG recording · Fourier analysis · Signal filtering · Computational physics · Biophysics · Electric Dipole Vector

APPROXIMATE PERFORMANCE TIME 1 Week

1 Learning Objectives

This experiment is part of a series of experiments being developed by Dr. Sabieh Anwar which aims at understanding physics of the human body. In this experiment, we will,

1. record ECG signals for a patient at rest as well as immediately after exercise,
2. understand the method of filtering the ECG signal,
3. understand the use and working of the QRS identification algorithm,
4. determine the power spectrum for ECG recorded before and after exercise, and finally
5. develop a preliminary understanding of the oscillating heart dipole model.

2 The Experiment

2.1 The Equipment

1. PhysLogger
2. V-Probe

3. Cables

- Type AC USB
- Type C-to-C USB
- BNC-to-banana

4. ECG Box (Contains a bio-potential measurement circuit and the circuit diagram is available on the experiment's website.)

5. Electrodes (green, yellow and red)

6. Transmission gel

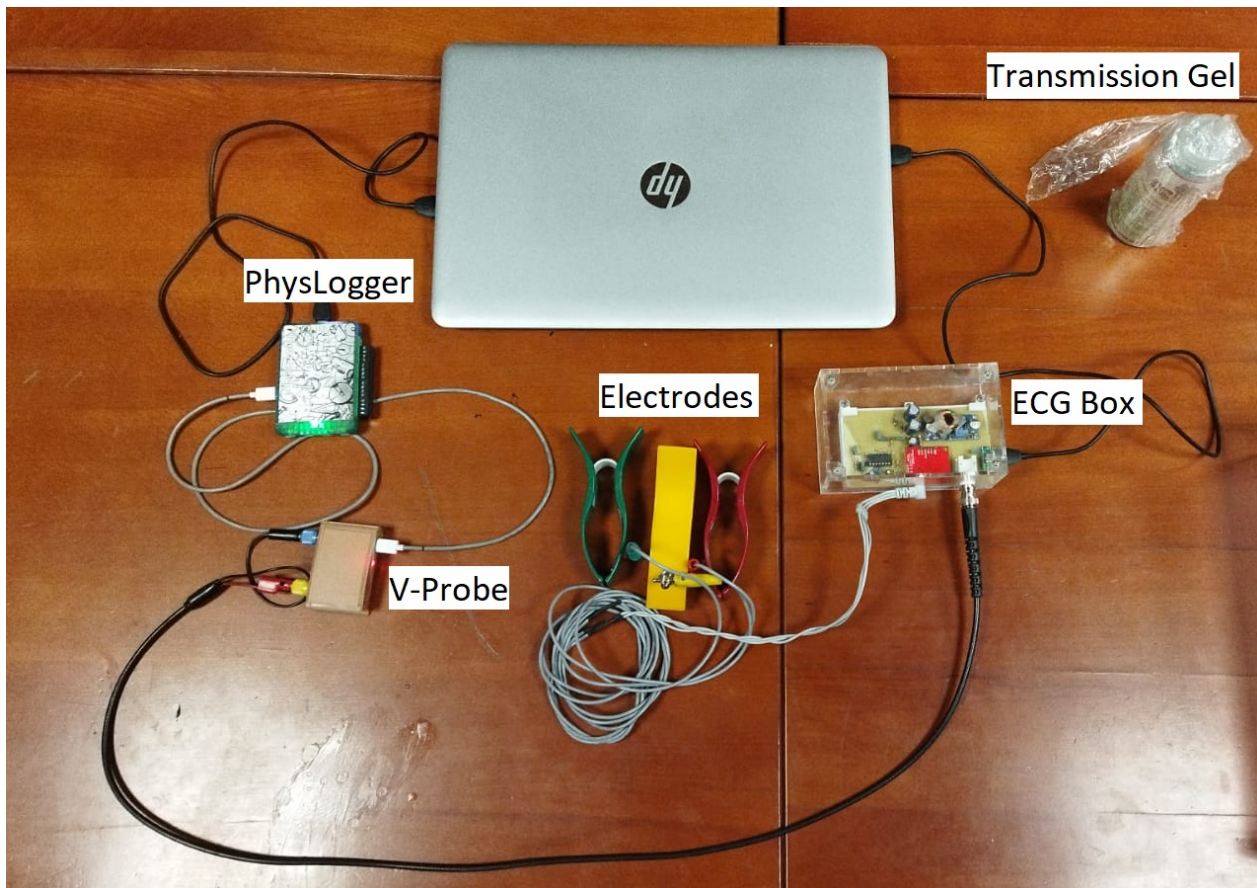


Figure 2: View of the ECG equipment connected together.

2.2 Preparation

- Verify that the PhysLogger Desktop App is installed on your computing device. Of course you need to know how it works and interacts with various instruments. You can learn more about it from our websites (<http://www.physlab.org/physlogger> or <http://www.physlogger.com>).
- Connect your computing device to the PhysLogger and set it up.

- Connect the V-probe to the PhysLogger and connect your device and the V-probe to the ECG box.
- Verify that the ECG box is receiving power and it is registering some noisy potential difference.
- The electrodes are color coded based on the location they are to be placed on the patient, refer to Fig. 3. Avoid placing the the electrodes on thick muscle and bone.
- Add transmission gel to the electrode before connecting to the patient and ensure that you connect the red electrode last.

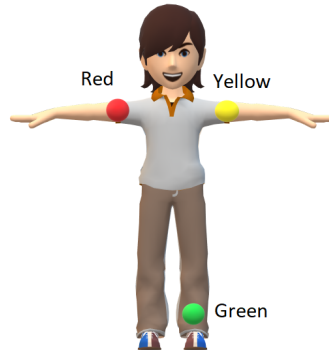


Figure 3: Color coded electrodes and their respective placements.

2.3 Data collection and Analysis

Set the sampling rate of PhysLogger to 100 Hz and take multiple reading, while the patient is at rest and after exercise. Record sessions lasting for about 45-60s and save the table with a suggestive name pattern.

For analysis, we will be using Google Colab, and Python extensions `numpy` and `biosppy`. From the experiment's website download the `ECGanalysis.ipynb`, which contains the program for ECG signal analysis. In Google Colab, select upload notebook option and the upload the `ECGanalysis.ipynb` file. Select the folder icon in the left bar followed by the upload icon to upload your recorded ECG signals. Once the files are uploaded, run the first cell and wait patiently for `biosppy` to be installed. Update the name of ECG signal file in the second block to match your corresponding naming strategy.

Read the relevant annotations along side each block to understand the process and the flow of the algorithm. The code should display the processed data which should be similar in form to Fig. 4.

2.3.1 FIR Filtration

The filtration used in the program corresponds to FIR (finite impulse response) with low-pass band-type [1]. The filter has a unit impulse response that has a limited number of

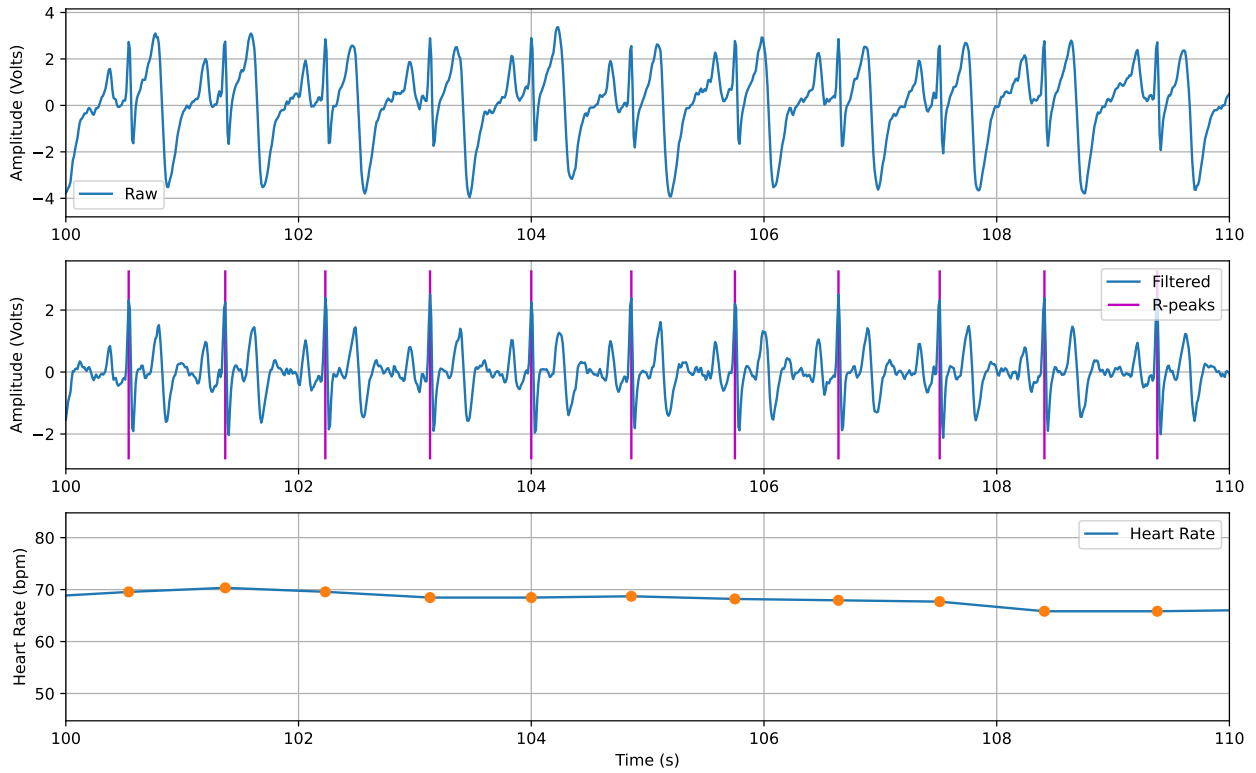


Figure 4: ECG summary for subject at rest: Top to bottom, original signal, filtered signal with marked R peaks and the instantaneous heart rate against time

terms each having a finite duration. This process is free of feedback and stable, hence is very effective for application on ECG signals. The low-pass filter on the other hand attenuates signal components that have frequency higher than threshold but does not disturb the rest contributing to the removal of outliers in the signal.

2.3.2 The QRS Detection

The QRS detection algorithm used in the program was proposed by Patrick Hamilton [3]. The following are some of his rules applied to the ECG signal:

- If a peak is larger than the detection threshold, it is a QRS complex
- Ignore all peaks that precede or follow larger peaks by less than 200 ms.

Notably the detection threshold is set based on the mean or median of the noise peak and QRS peak heights.

2.3.3 Power Spectrum

The original signal is a $V(t)$ function, and to find the power we need $V(f)$ which we achieve using a Fourier transform function from the `numpy` library. After transforming both axis we

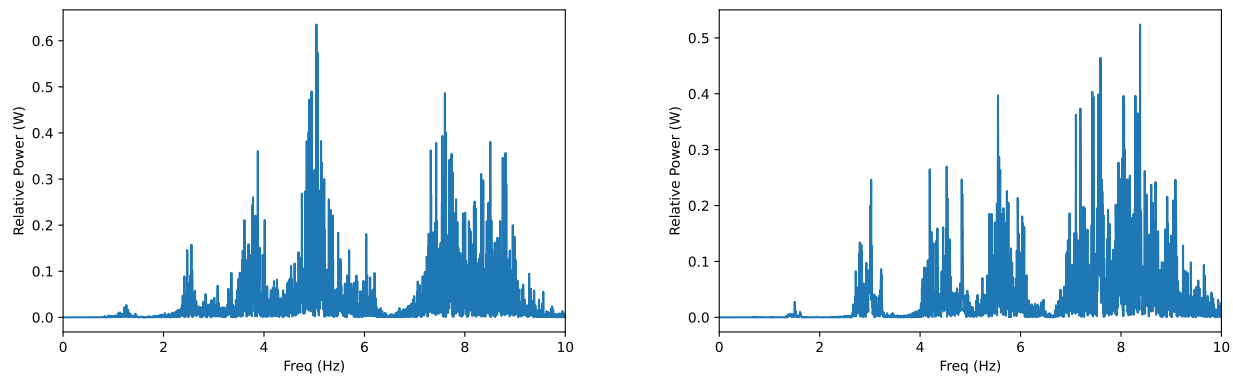


Figure 5: Power spectrum of a typical ECG at rest and after rigorous exercise, left and right respectively.

take the square of $V(f)$, which is a quantity with dimensions of power. We obtain typical power spectrum of the ECG signal shown in Fig. 5.

2.3.4 Heart Dipole Model

The relation of ECG and the heart dipole is illustrated in Fig. 6. For a visual representation of oscillatory motion of the heart dipole, refer to **ECGSIM**, an interactive ECG simulation tool, available on their website <http://ecgsim.org/>.

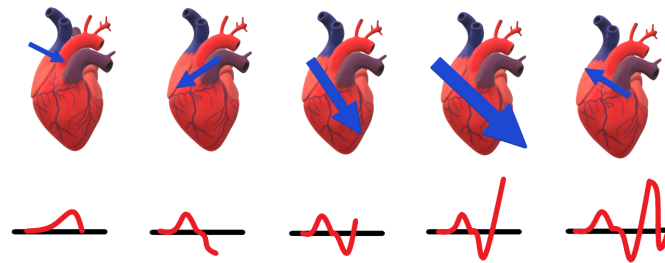


Figure 6: Relationship between the spread of cardiac electrical activation represented at various time instants by a summing vector (in the upper frames) and the genesis of the ECG (in the lower frames).

Q 1. Plot a histogram of heart rates and compare the histograms at rest and during exercise. What is the percentage change in the median heart rate for subject at rest and after exercise?

Q 2. Since the equipment is motion sensitive and requires the patient be stationary, try to find the shift in instantaneous heart rate while the patient is under strain. (Record while the subject performs a plank stand).

Q 3. Before you sign off form this activity, it is worthwhile to investigate how a typical QRS detection algorithm works.

References

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