VISVESVARAYA TECHNOLOGICAL UNIVERSITY
Jnana Sangama, Belagavi - 590 018

Internship / Professional Practice Report

on

Biomedical Signal Processing and Analysis

Submitted in partial fulfillment for the award of degree of

Bachelor of Engineering
in
Electronics and Communication Engineering

Submitted by

Aditya Venkata Sheshu
1RN18EC167

Internship carried out at
Defence Bio-Engineering and Electromedical Laboratory (DEBEL), Defence Research and Development Organization (DRDO)

Guide
Mr.Sanjay M Belgaonkar
Assistant Professor
ECE Dept.

External Guide
M.V Mallikarjuna Reddy
Scientist-'E' DEBEL
DRDO

DEPARTMENT OF ELECTRONICS AND COMMUNICATION ENGINEERING
(Accredited by NBA for the Academic Years 2018-19, 2019-20 and 2020-21)

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Channasandra,Dr.Vishnuvardhan Road,Bengaluru-560098

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Acknowledgement

The joy and satisfaction that accompany the successful completion of any task would be incomplete without thanking those who made it possible. We consider ourselves proud to be a part of RNS Institute of Technology, the institution which molded me in all endeavors.
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I extend my sincere thanks and heartfelt gratitude to my external guide **Mr.M.V Mallikarjuna Reddy**, Sc - 'E', Defence Bioengineering and Electromedical laboratory (DEBEL) - Defence Research and Development Organization (DRDO) for providing me invaluable support and guidance and suggestions throughout the period of my Internship.
I would like to sincerely thank everyone at **DEBEL , DRDO** for the wonderful opportunity and for being welcoming and supporting in the part of my internship at their prestigious organization and laboratory.
Finally, I take this opportunity to extend my earnest gratitude and respect to my parents, teaching and non-teaching staff of the department, who have directly or indirectly supported me during the period of my Internship.

Aditya Venkata Sheshu

Executive Summary

The internship carried out at DEBEL, DRDO was an interesting and insightful experience as I learnt and gained experience in a research environment pertaining to the topic of biomedical signal processing and analysis. The work carried out can be broadly classified into two parts based on the topics described as follows.

EEG Signal Processing : Electroencephalogram (EEG) signals , their characteristic properties as well as the methods of recording the signals and denoising was studied. The study performed ranges from the fundamentals of EEG signals and neural activity to understanding the concepts to analyze them followed by the denoising of EEG artifacts using the wavelet transform. Some of the key highlights include - The basic model of EEG data analysis, EEG Recording and interpretation, types of artifacts, frequency bands and EEG denoising.

ECG Signal processing : The study of Electroencephalogram(ECG) and its processing is done, and a project involving the concepts of the same is implemented . The project includes processing and detection of peaks of ECG signals followed by the calculation of BPM of a recorded ECG . The results obtained are observed and analyzed to understand the essential concepts involved in acquiring and processing ECG data to calculate essential parameters.

As the ongoing research work in these topic continues , the further scope of project work is also illustrated .

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Chapter 1

Introduction

1.1 Defence Bio-Engineering and Electromedical Laboratory (DEBEL) - DRDO

DEBEL is an Indian defence laboratory of the Defence Research and Development Organisation. Located in Bangalore, its main function is the research and development of technologies and products in the areas of life support, medical and physiological protection systems for the Indian Armed Forces. The laboratory is organised under the Life Sciences Directorate of the Defence Research and Development Organisation. It was formed in April 1976 by bringing together the Aero Electroengineering Unit of Aeronautical Development Establishment and the Electromedical Instrumentation Division of the Electronics and Radar Development Establishment, located nearby. Since 23 June 1992, the facility has been functioning at its own independent premises located at the Aeronautical Development Establishment campus.

Mission- To carry out design, development and evaluation of state-of-the-art life support and biomedical systems and devices,

Coordinate user evaluation and induction into Services,

Transfer technology for productionization,

Explore utilization of spin-off technologies for civilian application.

1.2 Products and Services

DRDO, the premier Research and development organization of the country, works on various areas of military technology to qualitatively address needs of Indian defense system. Since its establishment, DRDO has created major systems and critical technologies such as aircraft avionics, UAVs, small arms, artillery systems, EW Systems, tanks and armoured vehicles, sonar systems, command and control systems and missile systems.

The technology cluster of DRDO comprises of clusters of laboratories and centers specializing in products of various technological domains -

- Naval Systems and Materials (NS and M) - The cluster has developed state-of-the-art underwater sensors and surveillance systems; underwater weapons and associated systems Air Independent Propulsion systems; protection technologies for marine platforms, stealth and camouflage technologies for land, air and naval platforms, advanced metallic, ceramic, polymeric and composite materials for structural and functional application; and nuclear radiation management technologies.

- Aeronautical Systems (Aero) - engaged in the development of state-of-the-art unmanned Air Vehicles, Aero Gas Turbine Engine Technology, Airborne Surveillance Systems, Parachutes, Decelerators and Lighter-than-Air Systems.

- Armament Combat Engineering Systems (ACE) - ACE focuses on research and development of armaments, explosives, land based combat vehicles engineering equipment. Labs under this cluster are also involved in the production of systems through Transfer of Technology (ToT).

- Missiles and Strategic Systems (MSS) - MSS is responsible for the design and development of state-of-the-art Missiles and Strategic Systems required for the deterrence and defence of the country.

- Electronics and Communication Systems (ECS) - The ECS Cluster has a mandate to design and develop electronic, electro optical and laser based sensors and systems. he laboratories have developed state of art technologies in the fields of EW Systems, Radars, Electro optic Equipment, Laser Sources sensors, Directed Energy Weapon Systems and Communication Systems used in various Flagship Programmes and platforms of DRDO and ADA viz., Missile programmes, Unmanned Air Vehicles, Airborne Early Warning Control System, Aerostats, Main Battle Tank, Integrated Coastal Surveillance System and Light Combat Aircraft etc.

- Life Sciences (LS) - Equipping the Services with the best, cutting-edge weapon systems and platforms do not really achieve their intended purpose until the integral human component of the war machine is also optimized in terms of psychological, physiological and nutritional well being, with life support systems and protection from all conceivable operational hazards. It is in this very theatre that a group of laboratories in the DRDO comprising the Life Sciences(LS) cluster are focusing their RD efforts.

- Micro Electronic Devices, Computational Systems Cyber Systems (MED CoS).The MED CoS Cluster encompasses two areas viz. Micro Electronic Devices(MED) and Computational Systems Cyber Systems (CoS). The Micro Electronic Devices (MED) sub-cluster focuses on thrust areas and technologies relating to Microwave Tubes, Solid State Electronics including Micro Electronic device design and manufacturing.

1.2.1 Areas of Work - DEBEL

-

Defence Bio-engineering and Electromedical Laboratory (DEBEL) is involved in the Research and Development of Aeromedical engineering and biomedical technologies for ground soldiers, Aerospace and underwater operation; Percutaneous, respiratory and ocular protection against CBRN agents; Protective clothing and gears for pilots, submariners and combat vehicle crew and for troops deployed in extreme environments , Respiratory management systems for fixed and rotary-wing aircraft.

Some of its key products include -

- CBRN Defence
- Combat Free Fall System (CFF)
- HAPO Chamber

Chapter 2

Internship Introduction

2.1 Introduction

The internship at DEBEL - DRDO involves the study and implementation of signal processing concepts employed in medical device technology in the field of Biomedical engineering.

Biomedical engineering is the application of engineering principles and methods to solve medical and biological problems. With technology advancing and the demand for cutting edge medical equipment and devices expanding, it is a diverse, vital and rapidly growing field with Digital signal processing and data analysis bieng of immense importance in a biomedical engineering research.

Our bodies are constantly communicating information about our health. This information can be captured through physiological instruments that measure heart rate, blood pressure, oxygen saturation levels, blood glucose, nerve conduction, brain activity and so forth. Traditionally, such measurements are taken at specific points in time and noted on a patient's chart. Physicians actually see less than one percent of these values as they make their rounds—and treatment decisions are made based upon these isolated readings.

Biomedical signal processing involves the analysis of these measurements to provide useful information upon which clinicians can make decisions. Engineers are discovering new ways to process these signals using a variety of mathematical formulae and algorithms. Working with traditional bio-measurement tools, the signals can be computed by software to provide physicians with real-time data and greater insights to aid in clinical assessments. By using more sophisticated means to analyze what our bodies are saying, we can potentially determine the state of a patient's health through more noninvasive measures.Real-time monitoring can lead to better management of chronic diseases, earlier detection of adverse events such as heart attacks and strokes and earlier diagnosis of disease. Biomedical signal processing is especially useful in the critical care setting, where patient data must be analyzed in real-time.

The internship at DEBEL-DRDO involves the study, processing and analysis of Bio-medical signals pirticularly the EEG (Electroencephalogram) and ECG (electrocardiography) signals.

2.2 Introduction to EEG (Electroencephalogram)

An EEG is a test that detects abnormalities in your brain waves, or in the electrical activity of your brain. During the procedure, electrodes consisting of small metal discs with thin wires are pasted onto your scalp. The electrodes detect tiny electrical charges that result from the activity of your brain cells. The charges are amplified and appear as a graph/Signal on a computer screen, or as a recording that may be printed out on paper.

Clinically, EEG refers to the recording of the brain's spontaneous electrical activity over a period of time, as recorded from multiple electrodes placed on the scalp.Diagnostic applications generally focus either on event-related potentials or on the spectral content of EEG. For faster application, electrodes are mounted in elastic caps similar to bathing caps, ensuring that the data can be collected from identical scalp positions across all respondents.

Figure 2.1: An EEG Electrode cap

Any synaptic activity generates a subtle electrical impulse referred to as a postsynaptic potential. Of course, the burst of a single neuron is difficult to reliably detect without direct contact with it. However, whenever thousands of neurons fire in sync, they generate an electrical field which is strong enough to spread through tissue, bone, and skull. Eventually, it can be measured on the head surface.
EEG is most often used to diagnose epilepsy, which causes abnormalities in EEG

readings. It is also used to diagnose sleep disorders, depth of anesthesia, coma, encephalopathies, and brain death. EEG used to be a first-line method of diagnosis for tumors, stroke and other focal brain disorders,but this use has decreased with the advent of high-resolution anatomical imaging techniques such as magnetic resonance imaging (MRI) and computed tomography (CT).

2.3 Introduction to ECG (Electrocardiogram)

Electrocardiography is the process of producing an electrocardiogram (ECG or EKG). It is a graph of voltage versus time of the electrical activity of the heart using electrodes placed on the skin. These electrodes detect the small electrical changes that are a consequence of cardiac muscle depolarization followed by repolarization during each cardiac cycle (heartbeat). Changes in the normal ECG pattern occur in numerous cardiac abnormalities, including cardiac rhythm disturbances, inadequate coronary artery blood flow , and electrolyte disturbances. An electrocardiogram is a painless, noninvasive way to help diagnose many common heart problems in people of all ages. The overall goal of performing an ECG is to obtain information about the electrical function of the heart. Medical uses for this information are varied and often need to be combined with knowledge of the structure of the heart and physical examination signs to be interpreted. An ECG is used to see how the heart is functioning. It mainly records how often the heart beats (heart rate) and how regularly it beats (heart rhythm). It can give us important information, for instance about possible narrowing of the coronary arteries, a heart attack or an irregular heartbeat

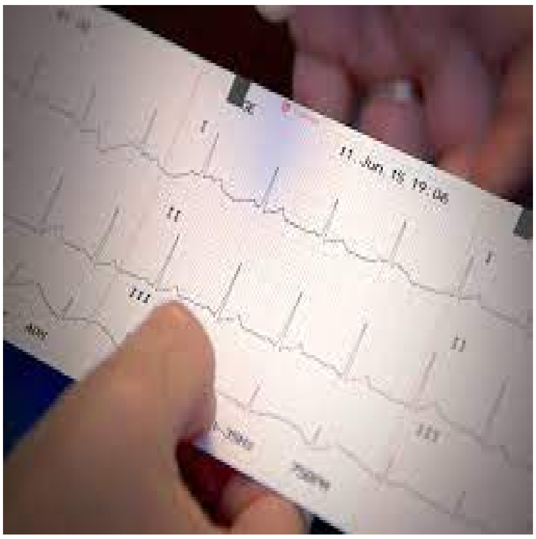

Figure 2.2: An ECG recording

An ECG gives two major kinds of information. First, by measuring time intervals on the ECG, a doctor can determine how long the electrical wave takes to pass through the heart. Finding out how long a wave takes to travel from one part of the heart to the next shows if the electrical activity is normal or slow, fast or irregular. Second, by measuring the amount of electrical activity passing through the heart muscle, a cardiologist may be able to find out if parts of the heart are too large or are overworked.

Chapter 3

A study on EEG and its processing

3.1 Significance of the electroencephalogram

Analyzing behavior and its underlying drivers requires a thorough understanding of the complexities of the human brain, both in structure and in function.Thanks to recent progress in imaging techniques, processor technologies, data analysis procedures and algorithms, both academic and commercial researchers are able to dive into the depths of the human brain and see how it shapes our perceptions and interactions with the world.

One of the most versatile brain imaging techniques is electroencephalography. Electroencephalography records the electrical activity of the brain using electrodes placed on the scalp. Measuring electrical activity from the brain is useful because it reflects how the many different neurons in the brain network communicate with each other via electrical impulses.[7]

3.2 The need for EEG Signal Processing

The brain contains unique information in many regions at any given time. An EEG signal recorded with electrodes placed on the scalp consists of many waves with different characteristics.The large amount of data recorded from even a single EEG electrode pair presents a difficult interpretation challenge. Signal processing methods are needed to automate signal analysis and interpret the signal phenomena.[6]

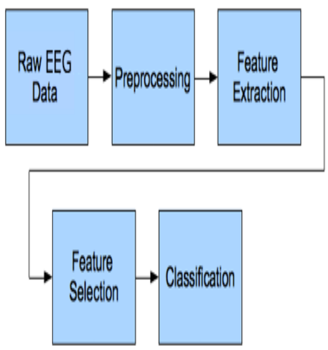

Figure 3.1: An EEG data processing model [7]

3.3 The Basic Model of EEG signal processing

In accordance to the above figure, an overview of processing data of an EEG can be described as follows -

1. **Preprocessing** : The first thing we need is some raw EEG data to process. This data is usually not clean so some preprocessing steps are needed. These often include the application of filters, such as a high-pass filter to remove the DC components of the signals and also the drifts (usually a frequency cut-off of 1 Hz is enough). A low pass filter can also be applied to remove the high frequency components. In EEG we currently rarely study frequencies above 90 Hz which correspond to the Gamma range (more on the EEG frequency ranges are illustrated in the following section).

2. **Feature Extraction** : Once the signals are clean, i.e. preprocessed, it is quite common to cut them in epochs of a few seconds and then extract features out of each one of these. This allows us to have a large number of features from a single EEG recording, which is always good when performing statistics or when applying classifiers. EEG signals are complex, making it very hard to extract information out of them using only the naked eye but thanks to computers, we can apply complex automatic processing algorithms that allow us to extract 'hidden' information from EEG signals. There are several techniques such as time domain features (mean, standard deviation, entropy, . . .), frequency domain features (Fourier transform, wavelets, . . .) , synchronisity features, which looks to the relationship between 2 or more EEG channels (coherence, correlation, mutual information, ...) and also EEG Tomography.

3. **Feature selection** : This step is optional and is used in the case in which we have a large number of features and we want to study the ones that are more relevant for our study. Consider looking for possible differences in the EEG in two different conditions: relaxed versus stressed. We can apply feature selection techniques to find out among our large number of features the ones that are more discriminative between these 2 conditions. We can apply statistical methods such as principal component analysis (PCA) or more complex techniques such as genetic algorithms.

4. **Classification** : Using machine learning techniques, we can train a classifier to recognise from among our features which ones belong to one class (or condition, i.e. relaxed,) or to another (i.e. stressed condition). This is a very powerful technique and it is extensively used in EEG data analysis. This is a major step in implementing brain computer interfaces (BCI).

3.4 Recording EEG signals

EEG systems use electrodes attached to the scalp to pick up electric potentials generated by the brain. Of course, you could just attach wires to the skin – however, this would create a very unstable electrical connection. Rather, opt for wet EEG electrodes. These are metal disks or pellets that connect with the skin via conductive gel, paste or cream, typically based on saline.

The right combination of electrode metal and conductive paste is important as some metals corrode rather fast, resulting in poor data.

Under optimal conditions, your skin, the electrode and the electrode gel function as capacitor and attenuate the transmission of low frequencies (slow voltage changes in the delta frequency range, for example). The most common wet electrode type is made of silver (Ag) with a thin layer of silver chloride (AgCl) – you will often find descriptions like Ag/AgCl electrodes.

Alternatively, you can use dry EEG electrodes. These make direct contact with the skin without requiring electrode gel. Typically, dry electrodes are much faster to apply, however at the same time are more prone to motion artifacts compared to wet sensors.

3.4.1 Interpreting the EEG data

As EEG monitors the time course of electrical activity generated by the brain, you can interpret which areas of the cortex are responsible for processing information at a given time:

Understanding information processing in the parts of the Brain -

Occipital cortex -

The occipital cortex is the visual processing center of our brain, located in the rearmost portion of the skull. All the things that we see are processed here (although some processing does also occur before and after the signal arrives). EEG experiments with visual stimuli (videos, images) often focus on effects in occipital regions.

Parietal cortex - The parietal cortex is all about integrating information stemming from external sources and internal sensory feedback from our body. The parietal cortex is responsible for merging all of these information sources into a coherent representation of how our body relates to the environment, and how all things (objects, people) in the environment spatially relate to us. Tasks requiring eye or hand movements as well as eye-hand coordination would be impossible without parietal cortex, which also processes, stores and retrieves the shape, size and orientation of objects to be grasped.

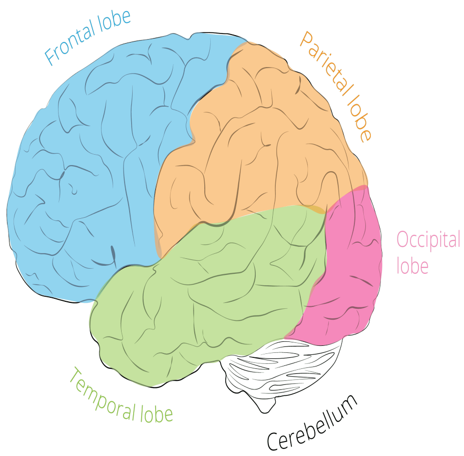

Figure 3.2: Brain lobes [7]

Temporal cortex -

The temporal cortex is associated with processing sensory input to derived, or higher, meanings using visual memories, language and emotional associations. The left temporal cortex is involved in the comprehension of written and spoken language. Medial (inner) regions are more active during spatial navigation.

Frontal cortex

The frontal part of the human brain is enlarged compared to most other mammals. Basically, the frontal cortex is all about executive function: it helps us maintain control, plan for the future, and monitor our behavior. Apart from the regional characteristics of where certain electrical activity originates, you can also analyze which frequencies primarily drive the ongoing activity.

3.4.2 Frequency Bands

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- Delta (1 – 4 Hz) Delta in sleep labs, delta waves are examined to assess the depth of sleep. The stronger the delta rhythm, the deeper the sleep. Increased delta power (an increased quantity of delta wave recordings) has also been found to be associated with increased concentration on internal working memory tasks.
- Theta (4 – 7 Hz) Theta is associated with a wide range of cognitive processing such as memory encoding and retrieval as well as cognitive workload Whenever we're confronted with difficult tasks (counting backwards from 100 in steps of 7, or when recalling the way home from work, for example), theta waves become more prominent. Theta is also associated with increased fatigue levels.

- Alpha (7 – 12 Hz) Alpha whenever we close our eyes and bring ourselves into a calm state, alpha waves take over. Alpha levels are increased when in a state of relaxed wakefulness. Biofeedback training often uses alpha waves to monitor relaxation. They are also linked to inhibition and attention.

- Beta band (12- 25 Hz) Oscillations within the 12 – 25 Hz range are commonly referred to as beta band activity (Niedermeyer da Silva, 2012). This frequency is generated both in posterior and frontal regions. Active, busy or anxious thinking and active concentration are generally known to correlate with higher beta power. Over central cortex (along the motor strip), beta power becomes stronger as we plan or execute movements, particularly when reaching or grasping requires fine finger movements and focused attention. Interestingly, this increase in beta power is also noticeable as we observe others' bodily movements.

- Gamma band (above 25 Hz) At the moment, gamma frequencies are the black holes of EEG research as it is still unclear where exactly in the brain gamma frequencies are generated and what these oscillations reflect. Some researchers argue that gamma, similar to theta, serves as a carrier frequency for binding various sensory impressions of an object together to a coherent form, therefore reflecting an attentional process. Others argue that gamma frequency is a by-product of other neural processes such as eye-movements and micro-saccades, and therefore do not reflect cognitive processing at all. Future research will have to address the role of gamma in more detail.

3.5 EEG Artifacts

One of the main concerns when dealing with electroencephalographic signals (EEG) is assuring that we record clean data with a high signal to noise ratio. The EEG signal amplitude is in the microvolts range and it is easily contaminated with noise, known as "artifacts", which need to be filtered from the neural processes to keep the valuable information we need for our applications Artifacts are signals recorded by EEG but not generated by brain.An artifact occurs when there is the noise registered by the system that contamines the neural EEG data EEG artifacts can be classified into physiological artifacts and artifacts from external sources.

physiological artifacts -

- 1. Muscle activity (EMG, ECG) - Muscle activity generates electric currents that are picked up by electrodes. The closer the muscles are to the electrodes, the stronger their impact on the recording will be. Particularly the activity of facial muscles (forehead, cheek, mouth), neck muscles and jaw musculature has severe effects on EEG recordings. Clenching should be avoided at all costs – instruct respondents to avoid chewing or tensing their jaw. As the heart is muscle, it also affects EEG data quality.

- 2. Eye movements - Eye movements (horizontal and vertical) affect the electrical fields picked up by the electrodes. Vertical eye movements (up-down) look more sinusoidal, while horizontal eye movements (right-left) look more box-shaped. The eye has a strong electromagnetic field that is established by the millions of neurons in the retina. Moving your eyes also shifts the electrical field generated by the eye ball. It's recommended to record eye movements using eye trackers or by placing additional EEG electrodes surrounding the eyes.
- 3. Blinks - Similar to eye movements, blinking interferes with brain signals quite a bit. If respondents blink while a certain stimulus is shown on screen, the EEG might not reflect the cortical processes of seeing the stimulus. As an EEG expert, you might tend to exclude this trial from the analysis since the EEG data does not contain relevant information. However, if blinking occurs non-systematically throughout the recording, attenuation based on statistical procedures such as regression and interpolation or Blind Source Separation might be more appropriate.

External sources of artifacts -

- Movement - Movement of an electrode or headset movements can cause severe artifacts that are visible in the affected channel or in all channels. Reasons for this are manifold: The EEG headset becomes loose, an electrode loses contact with the socket. It's always recommended to make sure that the headset sits snug on the head, and that all electrodes are securely attached to the skin.
- 2. Line Noise - Line noise (60 Hz in the US, 50 Hz in the EU) can have strong artifacts on the electrode recording – this becomes quite obvious in the raw EEG data. Particularly when impedances are poor, line noise is stronger. If the reference electrode is affected, the captured line noise is propagated to all other electrodes. Fortunately, the cognitive frequencies of the brain are often below the 50 or 60 Hz range, allowing you to filter your data accordingly or focus on the frequencies of interest.
- 3. Swaying and Swinging - Swaying and swinging can have strong effects on the recording. Especially head swinging or banging changes the water distribution, which affects the electrical properties and fields generated by the brain.

3.6 Denoising EEG Signals

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As illustrated in the above section, EEG signals become more complicated to analyze by the introduction of artifacts such as line noise, eye blinks, eye movements, heartbeat, breathing, and other muscle activities. Proper diagnosis of disease requires faultless analysis of the EEG signals. The problem of denoising is quite varied due to variety of signals and noise. One of the most revolutionary mathematical transformations, the Discrete wavelet transform provides effective solution for denoising non-stationary signals such as EEG due to its shrinkage property [4]. The present de-noising techniques that are based on the frequency selective filtering suffers from a substantial loss of the EEG data. Noise removal using wavelet has the characteristic of preserving signal uniqueness even if noise is going to be minimized. [3]

Apart from wavelet analysis , there are a number of denoisng techniques that can be employed to reduce the effect of the artifacts . They come with their own advantages and limitations and perform in a particular domain and for particular artifacts. These methods include regression, blind source separation, wavelet and empirical mode decomposition etc.[2] regression method works better for ocular artefacts than any other artefact. This becomes major limitation of this method if the signal is contaminated with other kind of artefacts. Apart from this, regression based methods depend on one or more EOG channel. Owing to this sometimes regression based artefacts eliminate the neural potential present in that EOG channel. The PCA method outperforms the regression based methods. When compared with regression based methods, PCA removes the artefact containing components more effectively, But PCA methods cannot completely removes the artefacts when these have comparable amplitudes. To enhance the level of denoising while preserving signal, one of most popular approach is to use combination of two or more existing methods. It is done such that the limitation of one method is overcome by another method with better result than individual method. These include PCA-ICA, wavelet-ICA and EMD-ICA. In these methods, generally, PCA, wavelet and EMD are used as preprocessing agent and ICA works for denoising of EEG signal

3.7 Further scope

The study of EEG and its signal processing is motivating to further understand and implement the concepts that go into analysing the beautiful human brain. EEG signals, as illustrated in the previous section contain artifacts and the techniques for artifact removal is a growing research field of Vital importance . Further scope of this study in the domain of EEG signals is to implement the denoising techniques and carry out project work and research for wavelet based denoising of EEG signals. The wavelet transform is a mathematical transformation of superior time-frequency localization. A potential research work and project revolves around the idea of comparing the efficiency of other promising noise removal techniques such as adaptive filtering and PCA with the wavelet transform analysis and also find the best wavelet that denoises an EEG significaantly.

Chapter 4

Project - ECG Processing and Heart rate calculation

4.1 Project overview

A project involving the concept of ECG signal processing was carried out under the title- ECG processing and heart rate calculation. In this project, ECG data of a subject is acquired and the heart beats per minute of the subject (BPM) is calculated upon processing of the ECG and computation of the detected number of peaks.

4.2 ECG Fundamentals

Below are some of the fundamental concepts underlying the project design

4.2.1 Recording the ECG

The electrical activity of the myocardium produces currents that flow within the body, resulting in potential differences across the surface of the skin that can be measured.Electrodes are conductive pads attached to the skin surface in order to measure this. A pair of electrodes that measure the potential difference between their attachment points, forms a lead. A wave of depolarization traveling towards a lead produces a positive deflection, and vice versa.

The magnitude and direction of reflection measured by a lead depends on the axis that it measures. By combining multiple leads, a more complete picture of the heart's 3-dimensional conduction can be viewed across multiple axes. The standard 12-lead ECG system is arranged as follows:

1. Limb Leads—I, II, III. Three electrodes are placed on the limbs: left arm (LA), right arm (RA), and left leg (LL). These electrodes then form leads I=LA–RA, II=LL–RA, and III=LL–LA. The virtual electrode Wilson's Central Terminal is the average of the measurements from each limb electrode.

2. Augmented limb leads—aVR, aVL, and aVF. These are derived from the same electrodes as used in the limb leads, and can be calculated from the limb leads. The

limb leads and augmented limb leads provide a view of the frontal plane of the heart's electrical activity.

3. Precordial leads—V1, V2, V3, V4, V5, V6. These leads measure the electrical activity in the transverse plane. Each lead measures the potential difference between an electrode placed on the torso, and Wilson's Central Terminal [3]

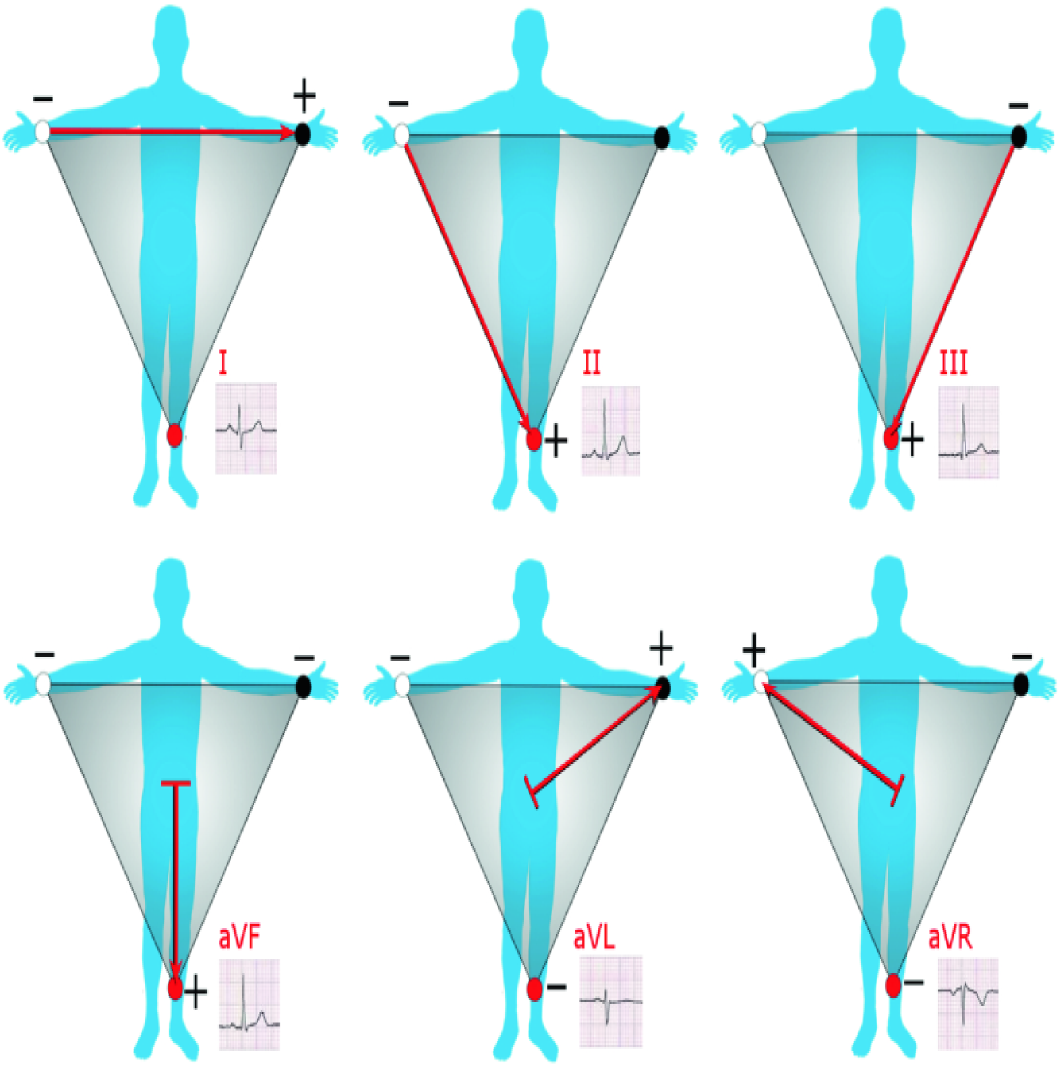

Figure 4.1: Frontal leads of the ECG

4.2.2 Interpretation of the ECG signal

The Normal ECG A normal ECG contains waves, intervals, segments and one complex, as defined below.

Wave: A positive or negative deflection from baseline that indicates a specific electrical event. The waves on an ECG include the P wave, Q wave, R wave, S wave, T wave and U wave.

Interval: The time between two specific ECG events. The intervals commonly measured on an ECG include the PR interval, QRS interval (also called QRS duration), QT interval and RR interval.

Segment: The length between two specific points on an ECG that are supposed to be at the baseline amplitude (not negative or positive). The segments on an ECG include the PR segment, ST segment and TP segment.

Complex: The combination of multiple waves grouped together. The only main complex on an ECG is the QRS complex.

Point: There is only one point on an ECG termed the J point, which is where the QRS complex ends and the ST segment begins.

The main part of an ECG contains a P wave, QRS complex and T wave. Each will be explained individually in this tutorial, as will each segment and interval.

The ECG signal recorded from a subject has a standard representation and can be broken down into segments for a structured assessment of the waves and intervals -

- The P wave represents atrial depolarization. Atrial systole begins after the P-wave onset, lasts about 100 ms, and completes before ventricular systole begins.
- The QRS complex represents ventricular depolarization. The ventricular walls have more mass and are thicker than the atrial walls. This, along with the angle and conduction flow of the ventricles relative to lead II, makes the QRS complex the most prominent feature shown in this ECG, and the target of most beat detectors. Atrial repolarization also occurs during this time, but is obscured by the large signal. Ventricular systole begins towards the end of the QRS complex.
- The T wave represents ventricular repolarization, and marks the beginning of ventricular diastole.

An ECG can convey a large amount of information about the structure of the heart and the function of its underlying conduction system, including: the rate and rhythm

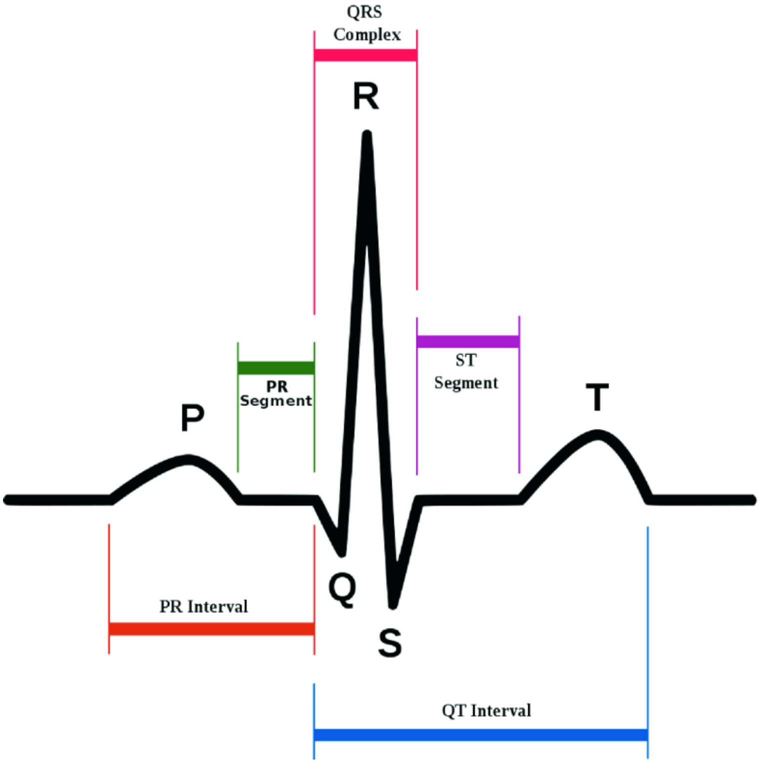

Figure 4.2: Frontal leads of the ECG

of heartbeats, the size and position of the chambers, and the presence of damage to the myocytes or conduction system.[3]

4.3 Software and hardware requirements

- PC\Laptop - 8GB RAM , WINDOWS\MAC OS
- MATLAB R2015a and above.

4.4 Project methodology

The project focuses on detecting R peaks of the ECG signal which is one of the most fundamental tasks in electrocardiogram signal processing. Upon acquisition of an ECG recording of a subject,there are some difficulties one can encounter in processing ECG such as irregular distance between peaks, irregular peak form, presence of low-frequency component in ECG due to patient breathing etc. To solve the task the processing pipeline should contain particular stages to reduce influence of those factors and obtain a computable and pure ECG waveform. The necessary processing is done to obtain a clear representation of the ECG peaks and further, the heart rate in beats per minute of the recorded ECG (BPM) is calculated.

4.4.1 Algorithm

- **Step 1** - Acquire ECG data
- **Step 2** - Convert to spectral domain to remove low frequecy components
- **Step 3** - preserve the significant peaks by threshold filtering
- **Step 4** - Adjust the window size and repeat filtering until a desirable quality of filtering is obtained
- **Step 5** - Calculate the heart rate by measuring the distance between R peaks

4.5 Project design and implementation

When the cardiac rhythm is regular, the heart rate can be determined by the interval between two successive QRS complexes.

Acquisition and low frequency filtering

First the ECG signal is sampled and converted into a vectored representation of data in MATLAB after which further computation such as filtering and thresholding is performed. once the ECG data is loaded, it is converted into its spectral representation upon applying the fast fourier transform. Before detecting the R peaks the ECG signal needs filtering and removal of low frequency components which is the purpose of implementation of the fast fourier transform. The Fourier transform is a mathematical transformation that relates a signal sampled in time or space to the same signal sampled in frequency, converting the signal from time to frequency domain. There exists many techniques to remove low frequency noise components from an ECG signal due to the presence of various noise signals such as baseline wander, powerline interference , EMG noise etc. Due to the incorporation of sampled time domain ECG data in this case we are simply removing the low frequency noise by thresholding after the implementation of the fast fourier transform (fft). Hence the unwanted low frequency components of the ECG is succesfully removed and the FFT filtered ECG obtained as shown below.

Window filtering and thresholding to detect the peaks

After removing the low frequency components of the ECG , the next step is to find the local maxima to represent the waveform in terms of peaks. A local maximum point on a function is a point (x,y) on the graph of the function whose y coordinate is larger than all other y coordinates on the graph at points "close to" (x,y). In order to perform this operation we use a windowed filter that "sees" only the maximum in the window and ignores all other values. a window function in signal processing terms, is a mathematical function that is zero-valued outside of some chosen interval, normally symmetric around the middle of the interval, usually near a maximum in the middle, and usually tapering away from the middle. Mathematically, when another function or waveform/data-sequence is multiplied by a window function, the product is also zero-valued outside the interval: all that is left is the part where they overlap, the "view through the window". Equivalently, and in actual practice, the segment of data within the window is first isolated, and then only that data is multiplied by the window function values. This function is coded in MATLAB where a window is applied to a portion of the ECG signal and the position of the maxima of that part is found. The highest point of the window is hence found representing it as a '1', preserving only the significant peaks of the ECG by then performing thresholding. This iteration repeats to determine all the maxima points in each window , moving on to cover the entire span of the measured ECG. Hence the peaks of the ECG are clearly detected and represented.

Heart rate calculation

The heart rate is the number of times the heart beats within a certain time period, usually a minute. There are two different rates that can be determined on an ECG. The atrial rate is indicated by the frequency of the P waves. The ventricular rate is indicated by the frequency of the QRS complexes. In the absence of disease, the atrial rate should be the same as the ventricular rate. the ventricular rate is sometimes determined based on the interval between the first two beats. However, it is obvious that the rate would have been faster had it been calculated using beats 2 and 3 (104 beats/min) because of a premature atrial beat, and slower if it had been calculated between beats 3 and 4 (52 beats/min). This illustrates an important point when calculating rate between any given pair of beats. If the rhythm is not regular, it is important to determine a time-averaged rate over a longer interval (e.g., over ten seconds or longer). For example, because the recording time scale is 25 mm/sec, if there are 12.5 beats in 10 seconds, the rate will be 75 beats/min. In this case we have coded to find the distance between the R peaks i.e the average distance between the first and last peaks of the ECG . The average heart rate in beats per minute is computed as - average Heart Rate = 60*sampling rate/average Distance Between Peaks.

While **Reading an ECG Strip** the interpretation is as follows-

ECG paper is a grid where time is measured along the horizontal axis.

- Each small square is 1 mm in length and represents 0.04 seconds.
- Each larger square is 5 mm in length and represents 0.2 seconds.

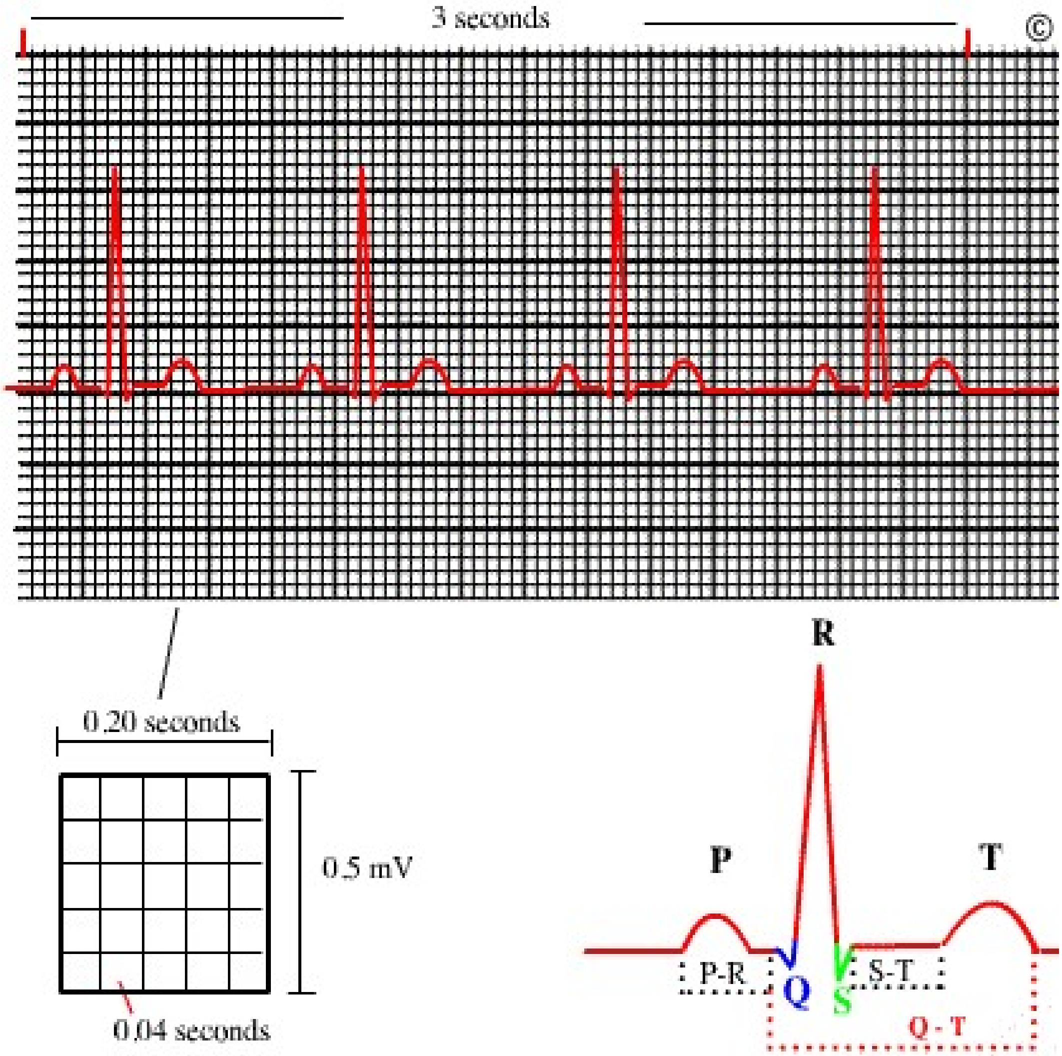

Figure 4.3: Inerpretation of an ECG strip [7]

Voltage is measured along the vertical axis.

- 10 mm is equal to 1mV in voltage.
- The diagram below illustrates the configuration of ECG graph paper and where to measure the components of the ECG wave form

calculation of heart rate from the ECG strip:

- When the rhythm is regular, the heart rate is 300 divided by the number of large squares between the QRS complexes.For example, if there are 4 large squares between regular QRS complexes, the heart rate is 75 (300/4=75).
- The second method can be used with an irregular rhythm to estimate the rate. Count the number of R waves in a 6 second strip and multiply by 10. For example, if there are 7 R waves in a 6 second strip, the heart rate is 70 (7x10=70).

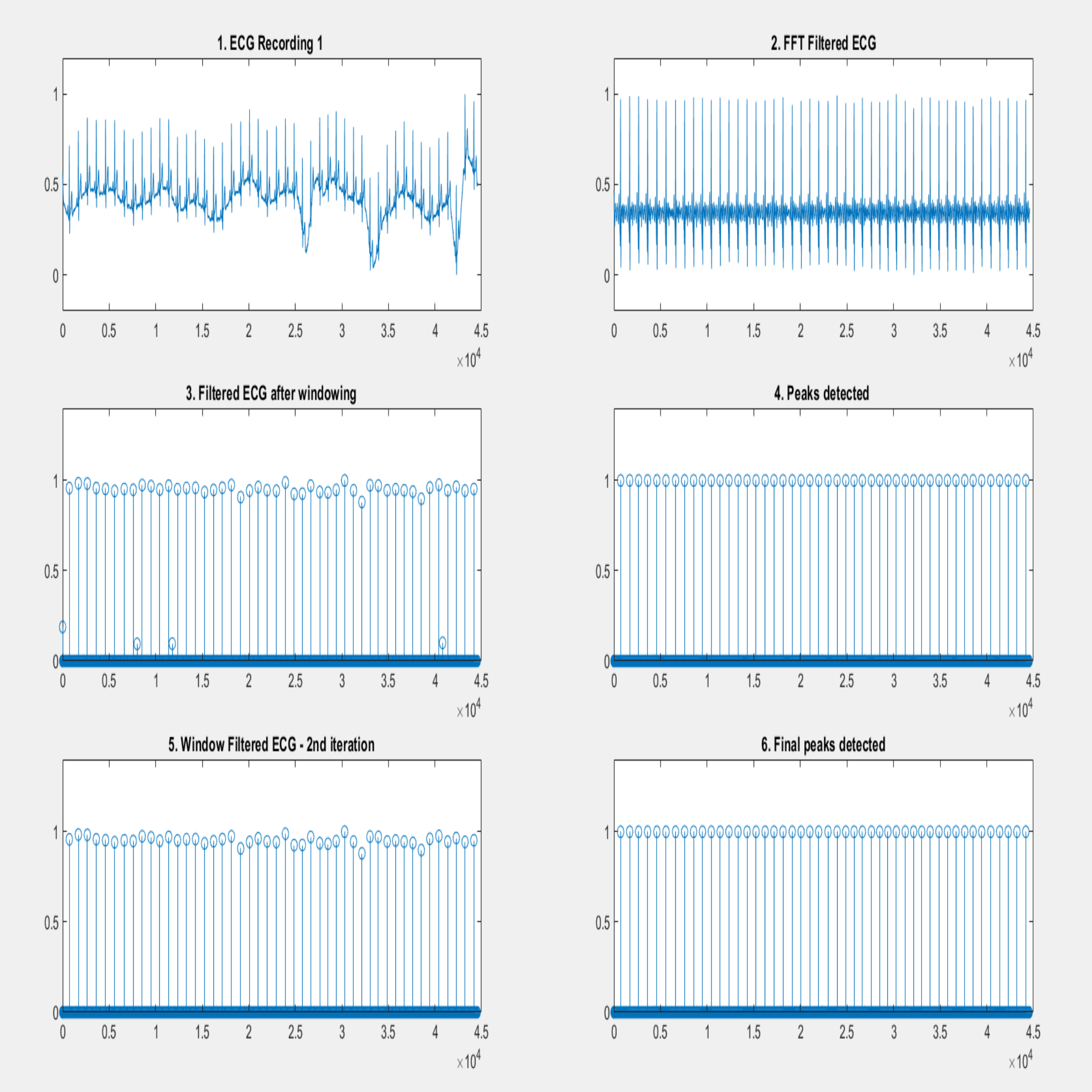

Figure 4.4: plots of ECG Recording - 1

4.6 Results

The peak detection and filtering process is performed on two ECG recordings. The filtered ECG upon transformation and removal low frequency component and also the peaks detected upon filtering and thresholding through the window function is illustrated . Below are the figures plotted in MATLAB for the two ECG recordings.

the below plots for the two ECG recordings illustrate the original ECG input signal , the computed FFT and removal of low frequency components from the ECG followed by the plot after the implementation of windowing to yiwld maximas and the peaks detected after thresholding , after each iteration of windowing.

The resultant ECG's highlighting the detected peaks can be seen below-

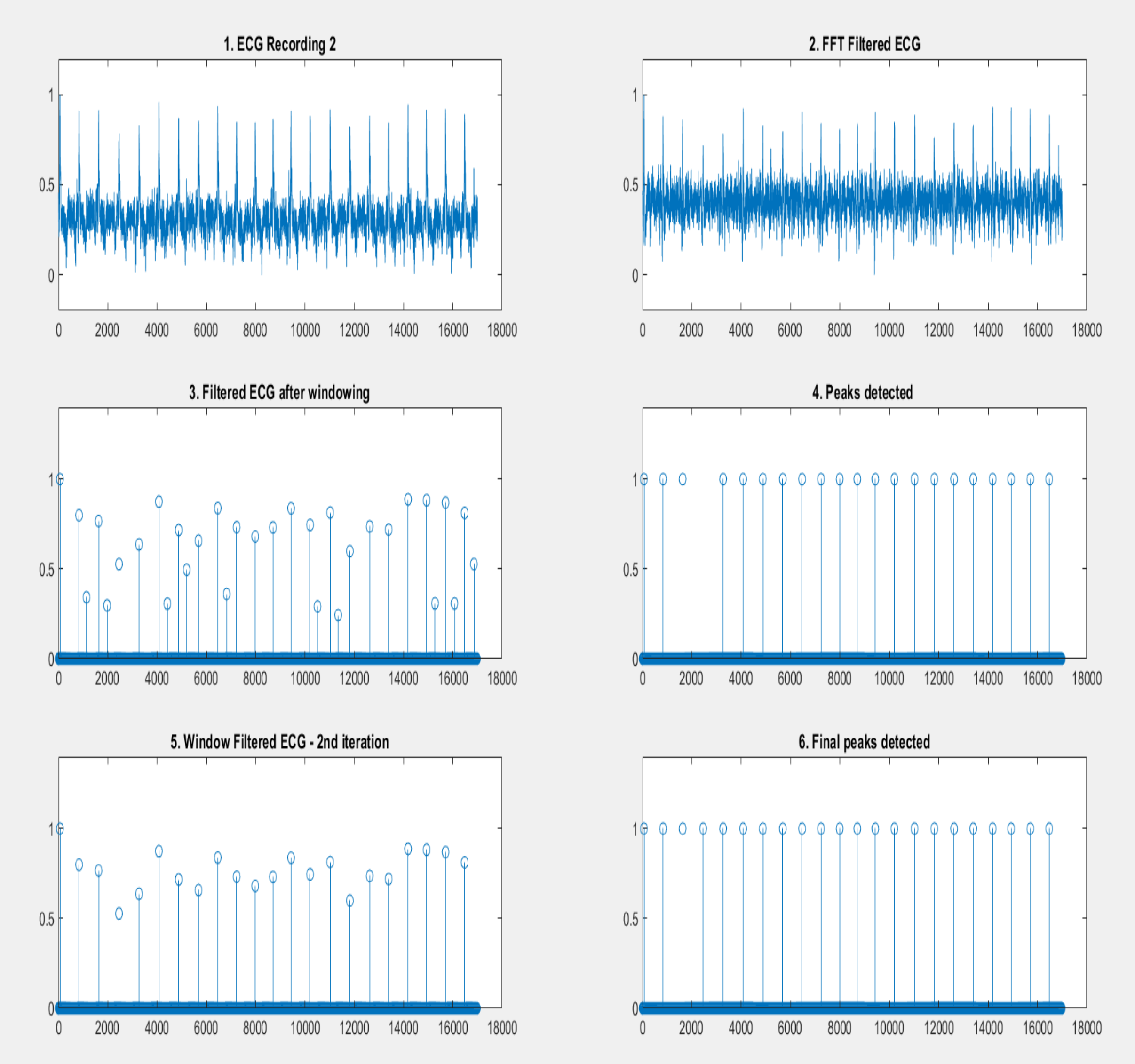

Figure 4.5: plots of ECG Recording - 2

The **heart rates** calculated in BPM (Beats per minute) of the two ECG's after peak detection are :

- ECG 1 : Average Heart Rate = 66.2314
- ECG 2 : Average Heart Rate = 81.2893

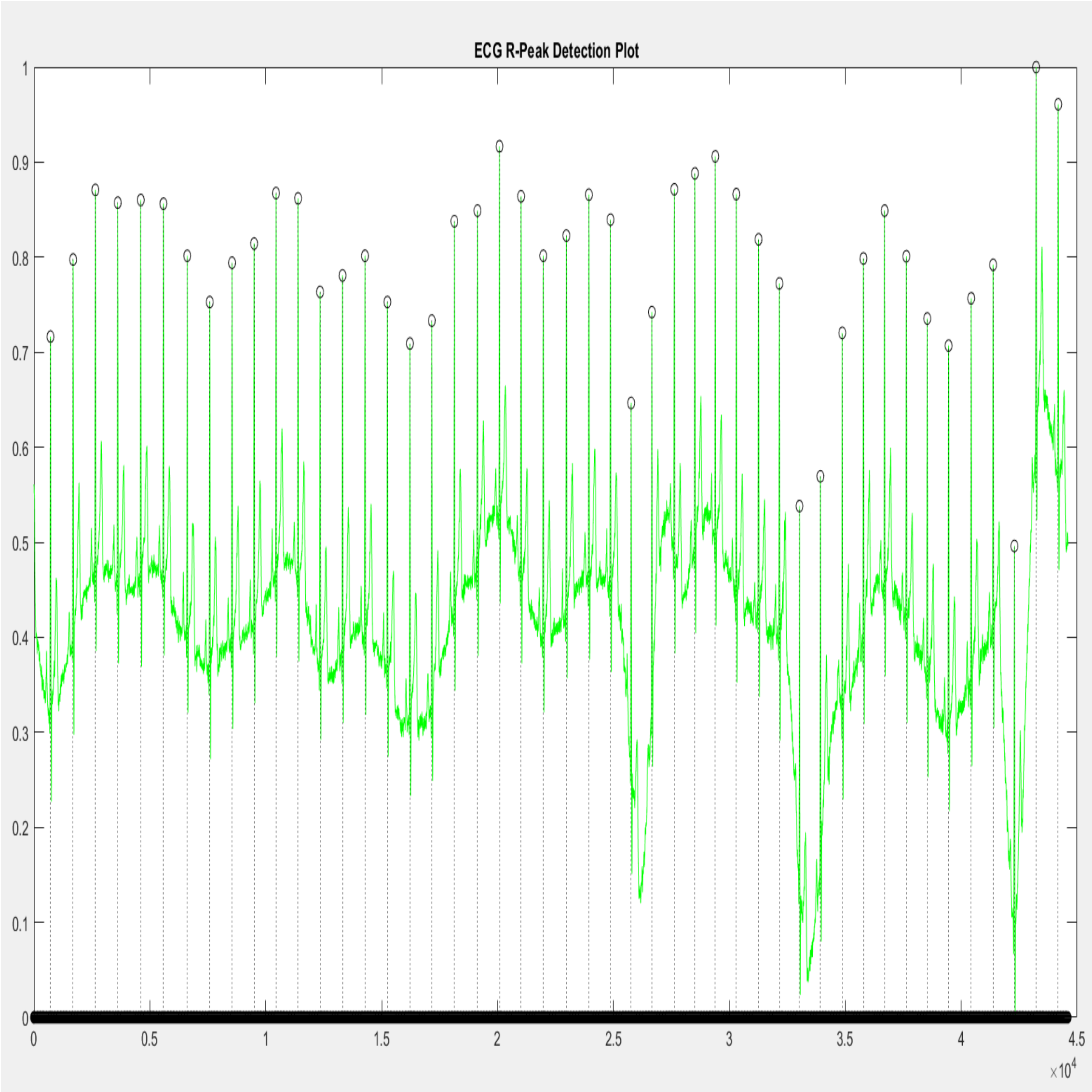

Figure 4.6: resultant peak detected ECG -1

4.7 Further Scope

Technology continues to play a huge role in medical diagnosis and understanding the significance of signal processing in biomedical fields is inspiring. Recently, heart diseases are increasing at a phenomenal rate and according to the world health organization (WHO) cardiovascular diseases are a major cause of death in developing countries. For this reason, monitoring and diagnosis of heart diseases are very important. This motivates for further research work in this field and the project work done in ECG leaves a smooth transition for the implementation of interesting signal processing concepts.

Wavelet based denoising of EEG - ECG signal denoising is a major preprocessing step which attenuates the noises and accentuates the typical waves in

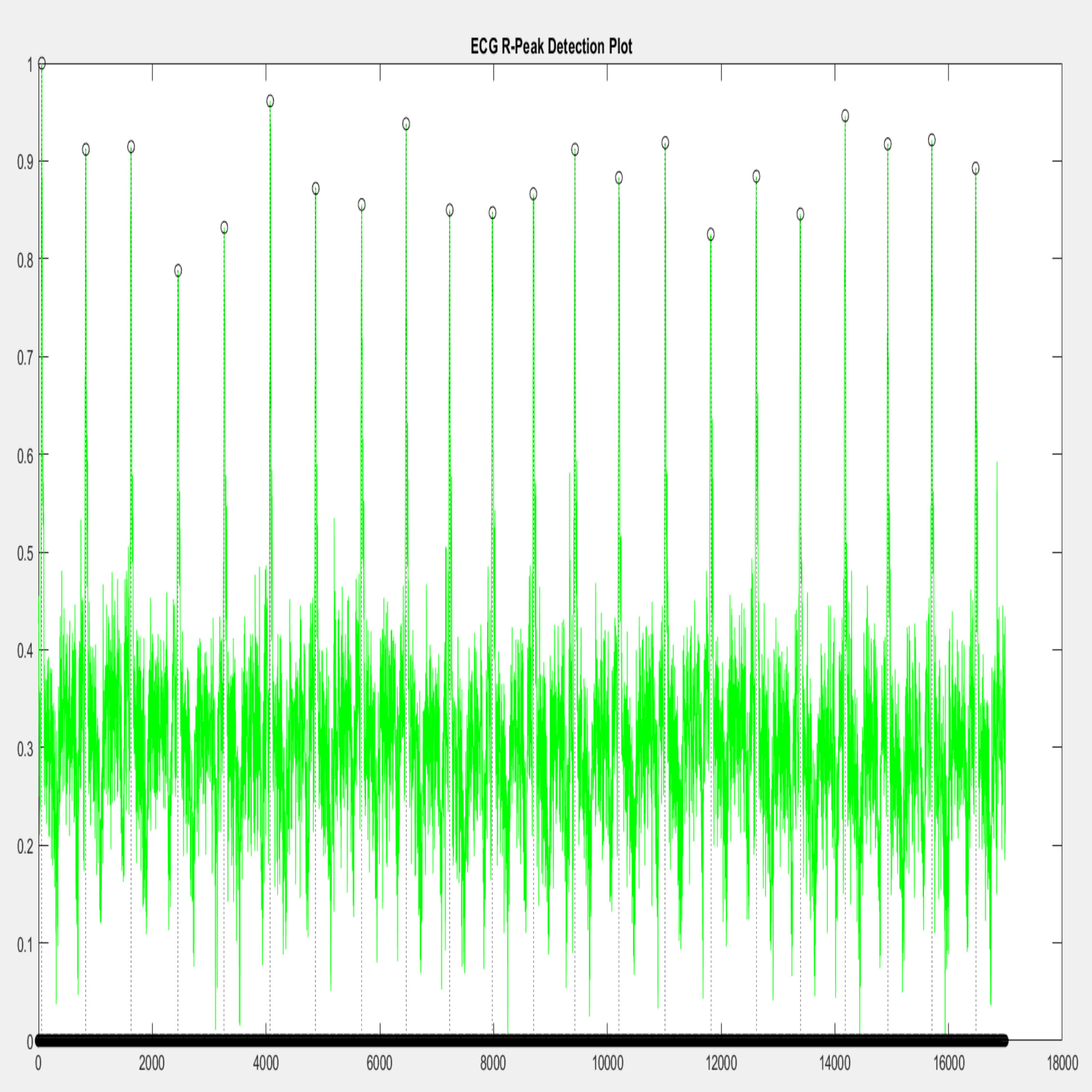

Figure 4.7: resultant peak detected ECG -2

ECG signals. Researchers over time have proposed numerous methods to correctly detect morphological anomalies. [1]. The wavelet transform is widely used by signal processing and biomedical engineers in denoising biomedical signals.

Ongoing research work following this project is finding a best suited wavelet for the implementation of the wavelet transform in order to denoise the ECG signals and also compare this technique with the already implemented denoising method involving window filtering to understand the difference in parameters such as computation time, accuracy, and signal to noise ratio .

Machine learning for biomedical signal processing is another intriguing and developing areas in biomedical technology and is regarded of vital importance with great research potential. Further scope from this project work is developing efficient

, fast algorithms for heart rate computation and incorporating machine learning concepts , deep learning frameworks and models to classify a variety of ECG data into regular and irregular heart rates and detect Cardiac arrhythmia

These are some of the ideas of potential research work and the next steps as work progresses from this project.

Experience and Conclusion

4.8 Internship Experience

My term of one month so far as an intern at DEBEL - DRDO has been a wonderful experience that has introduced and exposed me to the field of research in technology. The Defence Bio - engineering and electromedical laboratory (DEBEL) at the Aeronautical development establishment (ADE) campus of DRDO Bangalore, has state of the art equipments and facilities for pioneers to work thier craft on and develop essential , sophisticated and life saving products for the defence of the country . I'm grateful to have experienced the R&D atmosphere in this prestigious organization as I look forward to developing myself further in the field of signal processing.

4.9 Concluision

Coming to an end of the explanation and illustration of my work so far comprising of EEG and ECG signal processing, I conclude by expressing my gratitude to DEBEL - DRDO for giving me the opportunity to pursue my interests at their prestigious organization. I sincerely thank everyone who welcomed me and guided me at DEBEL ,making this a truly meaningful experience . I also thank my institution - RNS Institute of Technology for their invaluable support and guidance .

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