CHAPTER 1

INTRODUCTION

1.1 PREAMBLE

The electrocardiogram (ECG) is a measure of cardiac electrical activity generated by depolarization/polarization of the heart muscle. The ECG is a very important signal that is useful in heart rate monitoring and the diagnosis of cardiovascular diseases. The ECG typically exhibits both persistent features (such as the average PQRS-T morphology and the short-term average heart rate, or average RR interval), and non-stationary features (such as the individual RR and QT intervals, and long-term heart rate trends). The ECG gives two kinds of information. First, the duration of the electrical wave crossing the heart, which in turn decides whether the electrical activity is normal or slow or irregular and the second is the amount of electrical activity passing through the heart muscle which enables to find whether the parts of the heart are too large or overworked.

1.2 ECG SIGNAL ACQUISITION

The cardiac electrical activity is acquired through externally located surface electrodes that adhere to the skin. The electrodes detect the tiny electrical changes in the skin that arise from the depolarized heart muscle during each heartbeat. In clinical practice, the standard 12-channel
ECG is obtained using four limb leads and chest leads in six positions. The right leg is used to place the reference electrode. The six chest leads permit viewing the cardiac electrical vector from different orientations in a cross sectional plane (Rangayyan, 2002).

1.3 FEATURES OF ECG

Figure 1.1 illustrates the normal clinical features of the electrocardiogram, which include wave amplitudes and inter-wave timings. The ECG signal is characterized by five peaks and valleys labelled by the letters P, Q, R, S, T. In ECG an extra wave can be seen at the end of the T wave, and this is called as U wave and it may be due to repolarisation of the papillary muscles. The P-wave represents the activation of the upper chambers of the heart, the atria, while the QRS complex and T-wave represent the excitation of the ventricles or the lower chamber of the heart. The interval between the S wave and the T wave is called the ST segment. The horizontal segment preceding the P-wave is designated as the baseline or the isopotential line. Table 1.1 and Table 1.2 show the amplitude of different waves and duration of wave intervals respectively.

![Figure 1.1 Singlebeat of ECG](http://wikipedia/)
### Table 1.1  Amplitude range of ECG

<table>
<thead>
<tr>
<th>Name of the wave</th>
<th>Amplitude of the wave</th>
</tr>
</thead>
<tbody>
<tr>
<td>P-wave</td>
<td>0.25 mV</td>
</tr>
<tr>
<td>R-wave</td>
<td>1.60 mV</td>
</tr>
<tr>
<td>Q-wave</td>
<td>25% R wave</td>
</tr>
<tr>
<td>T-wave</td>
<td>0.1 to 0.5 mV</td>
</tr>
</tbody>
</table>

### Table 1.2  Duration of ECG

<table>
<thead>
<tr>
<th>Wave interval</th>
<th>Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>P-R</td>
<td>0.12 to 0.20 s</td>
</tr>
<tr>
<td>Q-T</td>
<td>0.35 to 0.44 s</td>
</tr>
<tr>
<td>S-T</td>
<td>0.05 to 0.15 s</td>
</tr>
<tr>
<td>P-wave</td>
<td>0.11 s</td>
</tr>
<tr>
<td>QRS</td>
<td>0.09 s</td>
</tr>
</tbody>
</table>

### 1.4 ARTIFACTS IN ECG

Any signal in ECG other than that of interest could be termed as an interference, artifact, or simply noise. The ECG is often contaminated by noise that can be within the frequency band of interest and can manifest with similar morphologies as the ECG itself. The source of noise could be physiological, the instrumentation used, or the environment of the
measurement. In general, the ECG is affected by the following artifacts (Clifford D et al, 2006).

i. Electrode pop or contact noise: Loss of contact between the electrode and the skin manifesting as sharp changes with saturation at FSD levels for periods of around one second on the ECG.

ii. Patient–electrode motion artifacts: Movement of the electrode away from the contact area on the skin, leading to variations in the impedance between the electrode and skin, causing potential variations in the ECG and usually manifesting themselves as rapid (but continuous) baseline jumps or complete saturation for up to 0.5 seconds. This can be avoided by placing the electrode properly or the patient is in a stationary position.

iii. Electromyography (EMG) noise: Electrical activity due to muscle contractions lasting around 50 ms between DC and 10 KHz with an average amplitude of 10% FSD level.

iv. Data collecting device noise: Artifacts generated by the signal processing hardware, such as signal saturation.

v. Electrosurgical noise: Noise generated by other medical equipment present in the patient care environment at frequencies between 100 kHz and 1 MHz, lasting for approximately 1 and 10 seconds;
vi. Quantization noise and aliasing: Noise introduced by the analog to digital conversion and Digital to analog conversion process.

vii. Signal processing artifacts: noise introduced by the Gibbs oscillations phenomenon and error due to the limitations in the arithmetic logic unit.

viii. Powerline interference (PLI): This occurs due to the stray effect of the alternating current fields due to loops in the patient’s cables causes powerline interference in ECG. PLI is the most commonly encountered periodic artifact in ECG at $50 \pm 0.2$ Hz or $60 \pm 0.2$ Hz with amplitude of up to 50% of full scale deflection (FSD) compared to the peak-to-peak ECG amplitude.

ix. Baseline wander (BW): The drift in the ECG signal from iso-electric line is known as Baseline wander. Baseline wander is caused by respiration, perspiration and varying impedance between electrode and skin due to poor skin electrode contact. Usually from respiration with an amplitude of around 15% FSD at frequencies drifting between 0.15 and 0.3 Hz

The artifacts except powerline interference and baseline wander can be avoided by having a proper recording equipments and proper recording environment. But powerline interference and baseline wander noise are present in almost all the signals, though the recording equipment and recording environment are proper. Hence, this research work mainly focus on the removal of baseline wander and powerline interference from ECG to
enable automated clinical diagnosis more accurate. The following sections
give detailed information about powerline interference and baseline wander.

1.4.1 Powerline Interference

![Powerline Interference](image)

**Figure 1.2** Powerline interference affected ECG

Figure 1.2 shows the PLI affected ECG signal. The powerline interference (PLI) may be due to stray effect of the alternating current fields due to loops in the patient’s cables. Other causes are loose contacts on the patient’s cable as well as dirty electrodes. When the machine or the patient is not properly grounded, powerline interference may even completely obscure the ECG waveform. PLI also caused by powerline of the measurement systems, despite proper grounding, shielding and amplifier design. PLI also can occur from the power cables of other nearby devices and gadgets in the recording room. Cables carrying ECG signals from the examination room to
the monitoring equipment are susceptible to electromagnetic interference (EMI) of power frequency (50 Hz or 60 Hz) by ubiquitous supply lines and plugs so much so that sometimes the ECG is totally masked by the PLI.

Electromagnetic interference from the powerline also results in poor quality tracings. The powerline interference corrupts the ECG with amplitude of up to 50% of full scale deflection (FSD), the peak-to-peak ECG amplitude (Clifford D et al, 2006).

1.4.2 Baseline Wander

![Baseline Wander noise affected ECG](image)

Figure 1.3 Baseline Wander noise affected ECG

Figure 1.3 shows the BW affected ECG signal. BW noise is caused by respiration, perspiration and varying impedance between electrode and skin due to poor skinelectrode contact. ECG BW noise bandwidth is in the
same range of ECG signal bandwidth. The bandwidth of the BW noise extends from 0 Hz to 0.8 Hz with amplitude of around 15% FSD at frequencies drifting between 0.05 Hz and 0.5 Hz. The frequency range of BW noise is similar to the frequency range of ST segments. BW noise distorts the low frequency ST segments of ECG signals that have strong clinical importance in the diagnosis of Acute Coronary Syndrome (ACS) (Sornmo & Laguna, 2006).

1.5 CHALLENGES IN ARTIFACT REMOVAL IN ECG

PLI is a high frequency additive noise (50 or 60 Hz) having low amplitude. The frequency of PLI overlaps the frequency content of the QRS complex. Hence, it can totally mask the signal of interest and make it difficult to locate the Q, S and T complexes. The performance of the ECG analysing system depends on the accurate and reliable detection of the QRS complex, as well as T and the P waves. The detection of the QRS complex is the most important task in automatic ECG signal analysis. Once the QRS complex has been identified, a more detailed examination of ECG signal including the heart rate, the ST segment etc. can be performed. So, the ECG denoising method should not corrupt the QRS complex.

The ECG is a low amplitude and low frequency signal. The amplitude of ECG ranges from 10µV to 5mV and frequency ranges from 0.05 Hz to 100 Hz. Any change in the amplitude or the frequency of the ECG makes the diagnosis of cardiac diseases more difficult. The presence of BW noise in ECG recording distorts the low-frequency ST segment of ECG signal that has strong clinical importance in the diagnosis of Acute Coronary Syndrome (ACS). A small elevation or depression in ST segment affects the diagnosis results of ACS, which is the primary cause of mortality. Hence, any change in
the amplitude of the ECG makes the diagnosis of the heart diseases more
difficult and not reliable.

Visual analysis of long-term (24 hours) Holter ECG is tedious
and operator dependent. Automated techniques have been developed in order
to facilitate the analysis of ECG signals. It is obvious that automated
techniques for detection of arrhythmias considerably reduce the amount of
time the operator needs to spend. Automated analysis of ECG signal is
essential for timely diagnosis and treatment of cardiac diseases, and intern to
save lives. Recently, in biotelemetry applications ECG monitoring and
diagnosis of cardiac diseases are done remotely and Holter ECG is used for
real time monitoring and diagnosis of heart diseases. ECG denoising is the
pre-processing step in the automated ECG analysis and real time monitoring,
diagnosis and arrhythmia detection. Hence, the ECG denoising algorithm
should be computationally more efficient and simple.

1.6 MOTIVATION

In India, 30% of the adults are at the risk of coronary heart
disease (CHD). ECG plays a major role in detection of CHD. During ECG
acquisition, various noise and artifacts are added to ECG and it corrupts the
useful information in the ECG. ECG denoising is the preprocessing step in
ECG monitoring and diagnosis of CHD. For monitoring, accurate diagnosis
and arrhythmia detection applications, the artifacts in ECG should be removed
without corrupting the useful information. Hence, there is a need for an
effective denoising method.

Most of the artifacts in ECG can be controlled by using proper
measuring equipment and controlled environment. But PLI and BW noise
cannot be controlled. PLI and BW noise are present in almost all the ECG signals. The frequency range of PLI and BW noise overlap the frequency of ECG signals. The presence of PLI and BW noise make the analysis and interpretation of ECG very difficult and affects the real time monitoring and arrhythmia detection. Hence, the elimination of BW noise and PLI from ECG signal is usually the necessary preprocessing step to enhance the performance of diagnosis of cardiac diseases and arrhythmia detection.

ECG belongs to the family of multi-component non-stationary signal (Tagluk ME & English MJ, 1997). Traditional filters consider the ECG as linear and stationary signal. Filtering the ECG signal using traditional filters may smooth and blur the QRS complex and affect the PQ and ST segments. Hence, the performance of traditional filters for ECG denoising is not effective. Hence, an effective denoising method is needed, which improves the denoising performance and should not corrupt the useful information in the ECG. EMD is a data driven adaptive method for the analysis of non-linear and non-stationary signal. EMD decomposes any data into a set of IMF components and a residue, which become the basis of representing the data. As the basis is adaptive, it usually offers a physically meaningful representation of the underlying processes and there is no need for harmonics; therefore, EMD is ideally suited for analyzing data from non-stationary and nonlinear processes.

1.7 SIMULATION AND EVALUATION ENVIRONMENT

MATLAB (version 7.8.0.347(R2009a)) is used for the simulation and evaluation of improved EMD based algorithms for removal of baseline wander and powerline interference in ECG.
1.8 OBJECTIVE OF THE RESEARCH

The objective of the research work is to develop improved EMD based algorithms for removal of powerline interference and baseline wander in ECG with the following requirements:

i. The algorithm should improve the denoising performance

ii. The algorithm should not distort or corrupt the useful information in ECG signal

iii. The algorithm should be computationally efficient to use in real-time ECG monitoring and arrhythmia detection and telemetry applications.

The proposed methods are tested using simulated ECG with 50 Hz PLI and MIT-BIH arrhythmia database signals with 60 Hz PLI. The proposed methods are also evaluated using BW noise signal available in the MIT-BIH noise stress test database with simulated ECG and MIT-BIH database ECG.

The performance of the proposed methods are measured and compared to NSRLMS method, Traditional filters, EMD method, EMD with wavelet method and EEMD method using Signal to Noise Ratio (SNR), Root Mean Square Error (RMSE) and cross correlation coefficient (CCR) parameter. The performance of the proposed method is subjectively compared using the difference signal. Computation time of various algorithms is measured using profiling functions.
1.9 ORGANIZATION OF THE THESIS

The introduction about ECG and the artifacts present in ECG are discussed in chapter 1. Chapter 2 gives the literature survey of the thesis work. Chapter 3 presents the improved adaptive filter based on Empirical Mode Decomposition algorithm for BW noise and PLI removal in ECG. Chapter 3 also discusses about the database and performance parameters in detail. Chapter 4 presents the improved adaptive filters based on Ensemble Empirical Mode Decomposition algorithm for BW noise and PLI removal in ECG. Chapter 4 also discusses about LMS algorithm and BLMS algorithm based on EEMD algorithm. Chapter 5 presents the Bivariate Empirical Mode Decomposition method for BW noise and PLI removal in ECG. Chapter 6 presents improved Ensemble Empirical Mode Decomposition for removal of BW noise and PLI in ECG. Chapter 7 discusses about the conclusion and future work of the thesis.