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Master of Science in

Computing System Engineering

Printing and Signing ECG Leads in PDF files

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ABSTRACT

This thesis is focused on Printing and Signing ECG (Electrocardiograph) Leads in PDF files. The most widely used signal in clinical practice is the ECG. ECG conveys information regarding the electrical function of the heart, by altering the shape of its constituent waves, namely the P, QRS, and T waves. In the cardiology domain, the recording of the resting 12-lead ECG continues to be the most commonly used laboratory procedure for the diagnosis of cardiac disease. In the first part describes the ECG pattern recognition and their classification using non-linear transformations and neural networks. Second part of the study consists of ECG Data processing and Recording System.

This study is oriented towards printing and signing ECG signal in Portable Document Format (PDF) owing to its importance, because it is a file format used to represent documents in a manner independent of application software, hardware, and operating systems.

In the results and discussion section requirements and the constraints that characterized the work development are presented, together with the design issues encountered and the solutions adopted. Finally Java development tools have been used to enable signing ECG leads on PDF file.

Keywords: ECG, PDF (Portable document format), ECG Leads, Java, Cardiology

SOMMARIO

Questa tesi si focalizza sulla stampa e firma in file PDF delle derivazioni ECG. Il segnale più usato nella pratica medica è l'ECG. L'ECG trasmette informazioni riguardanti la funzione elettrica del cuore, modificando la forma delle sue onde, chiamate le onde P, QRS e T. Nel dominio cardiologico, la memorizzazione delle 12 derivazioni standard continua ad essere la procedura di laboratorio più comunemente utilizzata per la diagnosi di malattia cardiaca.

La prima parte dello studio descrive il riconoscimento di un pattern ECG e la sua classificazione usando trasformazioni non lineari e reti neurali. La seconda parte dello studio è costituito dal trattamento dei dati ECG e il sistema di memorizzazione. Più in dettaglio questo studio è orientato alla stampa e firma del segnale ECG in PDF, perché è un formato utilizzato per rappresentare documenti in modo indipendente dai software applicativi, dall'hardware e dai sistemi operativi.

Nella sezione dei risultati, i requisiti e i vincoli che hanno caratterizzato il lavoro di sviluppo sono stati presentati insieme ai problemi di progettazione incontrati e le soluzioni adottate. Infine, strumenti di sviluppo java sono stati utilizzati per consentire la firma delle derivazioni ECG in file pdf.

Parole Chiave: ECG, PDF (Portable document format), ECG Leads, Java, Cardiologia

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CHAPTER – ONE

INTRODUCTION

Information and communication technologies have grown rapidly during the last decades and are vastly used in every aspect of human activity. In healthcare environment like primary care and hospitals, the most visible technological developments of the last thirty years are electronic health records, telemedicine, bio-signal processing, medical image interpretation, and knowledge processing. The wide spread use of bio-signal acquisition devices in daily life applications, generated and continues to generate large amounts of bio-signals. Following the pervasive healthcare directions, access to bio-signals has been diversified and is no longer restricted to the hospital domain. Therefore, research resources are fostered and research community promotes the need to extract new knowledge from bio-signals towards the adoption of new medical procedures. In the cardiology domain, the recording of the resting 12-lead ECG continues to be the most commonly used laboratory procedure for the diagnosis of cardiac disease. As a record of the electrical activity of the heart, it is a unique technology that provides information not readily obtained by other methods [1]. However, ECG bio-signals are not efficiently managed, mainly due to the diversity and heterogeneity of the various storage formats. ECG devices traditionally record ECGs in binary formats which are mainly proprietary, thus not inter- operable and comprehensible. Consequently, meaningful ECG data analysis is impeded, also considering that most data formats do not provide the means to store, the equally important, context and content meta-data of the signal. Bio-signal context refers to information about patient demographics, diagnosis, recording equipment, researcher/investigator, etc., while annotation and interpretation information constitute part of the bio-signal content. Retrieving bio-signal metadata from other sources (if data are available and procedures are feasible) is often a prohibiting factor for important meta-analysis of the bio-signal [2].

1.1 The Electrocardiogram

Electrocardiogram (ECG) is the most used exam providing an interpretation of the heart's electrical activity. In practice, it records by skin electrodes the voltage of different body's points, these measures (or leads) are then represented as twelve graphs of the recorded voltage vs time. There are many exams that can be done to study the heart behavior; the ECG is largely used since it is a non invasive and inexpensive one. The voltage between the body surface's points is measured by the electrocardiograph, i.e. the device that allows doing an ECG, and it is printed on a display, called electro cardio scope, or on a so-called graph paper. Figure 1.1 shows the first ECG lead in a healthy case. The different waves we can see are called (from left to right) P, Q, R, S, T and U waves. The P wave represents the auricular depolarization, the QRS complex represents the ventricular depolarization, the segment QT is the plateau of the ventricular action potential, the T wave corresponds to the ventricular repolarization and the U wave (generally absent) is due to a mechanical factor that corresponds to the myocardium relaxation.

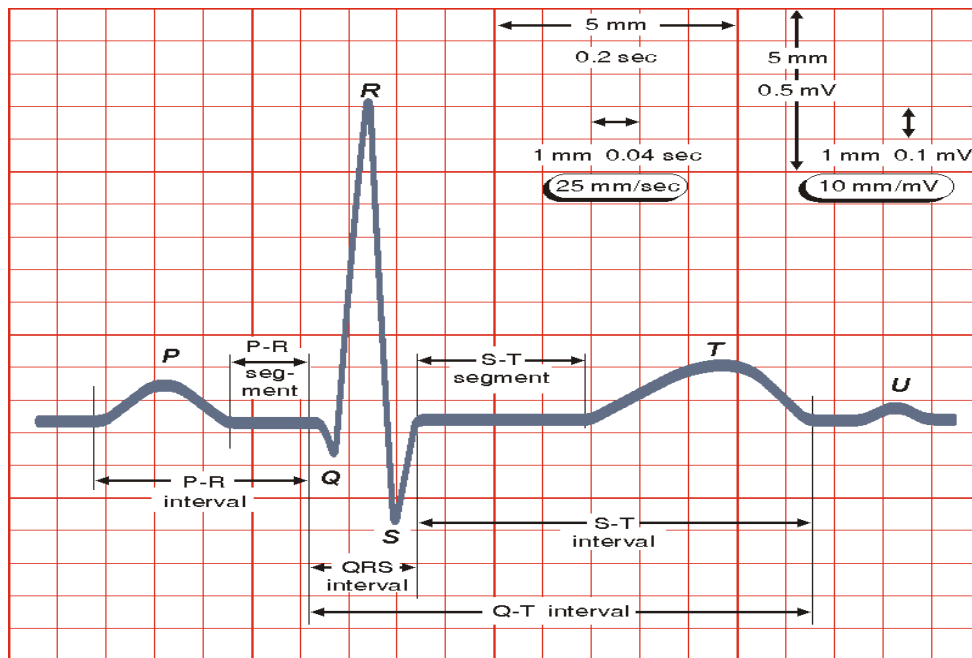


Figure 1.1: The Normal Electrocardiogram

An electrocardiogram (ECG) signal is a non-invasive measurement that provides information of a heart's physiologic function and myocardium electric activity. By placing electrodes on

the body surface, a twelve-lead electrocardiograph is employed to record the electrical activity. Cardiac arrhythmias are not fatal but may require therapy to prevent further problems. An ECG signal shows an almost periodic signal, and can provide symptomatic information in the dysfunction duration. A typical ECG signal consists of the P-wave, QRS-complex, and T-wave, which is the result of the electrical activity that propagates within the heart and causes the cardiac muscle to contract. Each cardiac disease affects permanently, temporarily, or partially the ECG waveform. The QRS-complex varies with rhythm origin and conduction path of the activation pulse in the heart. When the activation pulse originates in the atrium and travels through the conduction system, the QRS complexes have a sharp and narrow deflection. When the activation pulse does not travel through the normal conduction path, the QRS-complex becomes wide. In the time-domain technique, ECG features include heartbeat interval (R–R interval), wave amplitude (QRS, ST), duration parameters (Q–R–S, Q–T, and P–R), and combined parameters (Q/R ratio, S/R ratio).

However, some types of heartbeats occupy similar ranges of ECG parameters; therefore it is difficult to distinguish normal and ill heartbeats, resulting in misclassification. In the time-frequency technique, the wavelet transform (WT) has been employed to extract the features of cardiac arrhythmias using discrete wavelet transform (DWT). WT is robust to time-variant signal analysis and provides a reference wavelet with different dilation and translation parameters to signal processing and event detection [3].

1.2 ECG leads

It is important to remember that 12-lead ECG provides spatial information about the heart's electrical activity in 3 approximately orthogonal directions:

- ◆ Right ↔ Left
- ◆ Superior ↔ Inferior
- ◆ Anterior ↔ Posterior

Each of the 12 leads represents a particular orientation in space, as indicated below (RA = right arm; LA = left Arm; LF = left foot):

- ◆ Bipolar limb leads (Frontal plane):
 - ◆ Lead I: RA (-) to LA (+) (Right Left , or lateral)

- ◆ Lead II: RA (-) to LF (+) (Superior Inferior)
- ◆ Lead III: LA (-) to LF (+) (Superior Inferior)
- ◆ Augmented unipolar limb leads (frontal plane):
 - ◆ Leads aVR : RA (+) to [LA & LF](-) (Rightward)
 - ◆ Leads aVL : LA (+) to [RA & LF](-) (Leftward)
 - ◆ Leads aVF : LF (+) to [RA & LA](-) (Inferior)
- ◆ Unipolar (+) Chest leads (horizontal plane):
 - ◆ Leads V1, V2, V3 : (Posterior Anterior)
 - ◆ Leads V4 , V5, V6 : (Right Left , or lateral) [4]

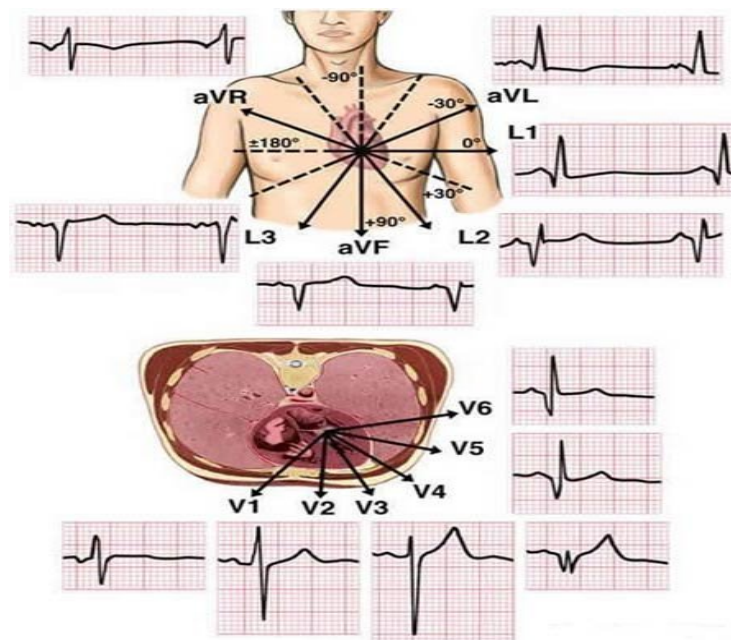


Figure 1.2: The basis of 12-lead ECG placement rules

1.3 The need for 12-lead ECG

Coronary Heart Disease (CHD) caused over 135,000 deaths in the UK in 1998 (Peterson et al., 2000). Each minute is critical for a patient with CHD or complaining of chest pain. Rapid and

accurate diagnosis of such patients is of utmost importance thrombolytic drugs in case of a suspected cardiac problem. Part of this assessment relies on the use of a 12-lead ECG to confirm or refute the diagnosis. The assessment criteria used to determine whether or not thrombolysis is carried out include a number of features observable from an ECG such as abnormal ST elevation, QRS width, and atrioventricular block (JRCALC, 2001; EMAS, 2002). Important clinical decisions will be made upon the basis of these assessments, and whether or not the ECG was performed correctly is crucial.

Key to the successful implementation of this programme will be the quality of the staff delivering the treatment. This will depend to a great extent on the appropriateness of nurses, paramedics and A&E staff, as well as on the training they receive. The executive summary clearly specifies that “those responsible for education will be expected to provide opportunities which help put the NSF into practice” (DoH, 2000, p. 11). Errors made in taking the ECG, such as the misplacement of electrodes can cause incorrect interpretation, misdiagnosis, and subsequent improper treatment of the patient (Heden et al., 1995; Pastor et al., 2001). Educational processes and tools which permit students to gain a high level of competence in this area are therefore vital. However, as it has already been highlighted, there is currently no adequate training tool to help the acquisition of these skills as one comprehensive package. Current full body simulators rely mainly on the intervention of the trainer to assess the action taken by the students and make the appropriate change, and screen-based simulators do not offer the required level of realism needed to acquire the physical examination skills to appropriately locate the ECG electrodes. There is therefore a need for an efficient training tool to replace the use of real persons to teach 12-lead ECG monitoring techniques. The ideal teaching tool for the placement of ECG electrodes would consist of a realistic mannequin generating ECG waveform according to the positioning of each electrode [5].

1.4 The Recording of ECG Signal

ECG has certainly the longest tradition in bio-signal monitoring and recording, because it is a strong (amplitude near 1mV) and relatively robust signal [6]. Electrocardiography can be monitored with various lead setups for diagnostic or treatment related purposes (e.g. signs of ischemia or heart attack, response to medication) in the clinic, in a general physician’s office, and even at home or during the activities of daily life, with relatively simple and inexpensive devices. In order to draw conclusions based on the signals, patient specific characteristics, i.e.

the context of the signal measurement, as well as information characterizing signal's content, i.e. detection of specific temporal events or signal features, would be required. In general, virtually unified content based querying of different sources of bio-signals can be regarded as a step towards further signal processing and analysis. Additionally, studying a plethora of carefully annotated bio-signals can support human users or computer algorithms to extract new knowledge from specific signal patterns. ECG -lead recording system will be described in chapter (3).

CHAPTER – TWO

ECG Pattern Recognition and Classifications

2.1 ECG Pattern Recognition

ECG processing techniques have been proposed to effect pattern recognition, parameter extraction, spectro temporal techniques for the assessment of the heart's status [7], de noising, baseline correction and arrhythmia detection. As we described in introduction ECG consists of three basic waves, the P, QRS and T (Figure 1.1). These waves correspond to the far field induced by specific electrical phenomena on the cardiac surface, namely atrial depolarization (P wave), ventricular depolarization (QRS complex) and ventricular depolarization (T wave). Numerous techniques have been developed to recognize and analyze these waves ranging from digital filtering techniques to neural network (NN) and spectro-temporal techniques [7,9]. A great deal of research has been devoted to digital processing of the ECG waves, particularly QRS, P and T wave detection (Figure 2.1). The P wave detection is still an open problem (especially in the presence of noise and in the case of supra ventricular tachycardia's).

However, QRS and T wave detection techniques have been developed, which give in most cases clinically acceptable results. In particular, arrhythmia analysis has received a great deal of attention, directed mostly to QRS: PVC classification and supra ventricular arrhythmias. In recent years, interest has shifted from arrhythmia to ischemia detection and monitoring. In ischemia, there is decreased blood flow to parts of the myocardium, due to vessel occlusion or muscle injury [8]. This causes depolarization of the resting membrane potential of the ischemic region with respect to the resting membrane potential of the normal region. This potential difference causes the flow of an injury current which is manifested in the ECG by an elevated or depressed ST segment (Figure 2.1) [10]. ST segment detection and characterization is a major problem in ECG processing due to inhibiting factors such as slow baseline drift, noise, sloped ST changes, patient dependent abnormal ST depression levels, and varying ST-T patterns in the ECG of the same patient. A number of methods have been proposed in the

literature for ST detection based on digital filtering, analysis of the first derivative of the signal, and syntactic methods. These methods tend to measure specific parameters (such as degree of depression, ST-T duration, etc.) in ways critically dependent upon the correct detection of the J point on the ECG, which is the inflection point following the S wave. In many cases, however, where the ST segment is sloped, or the signal is noisy, it is impossible to identify this point with reliability (Figure 2.1).

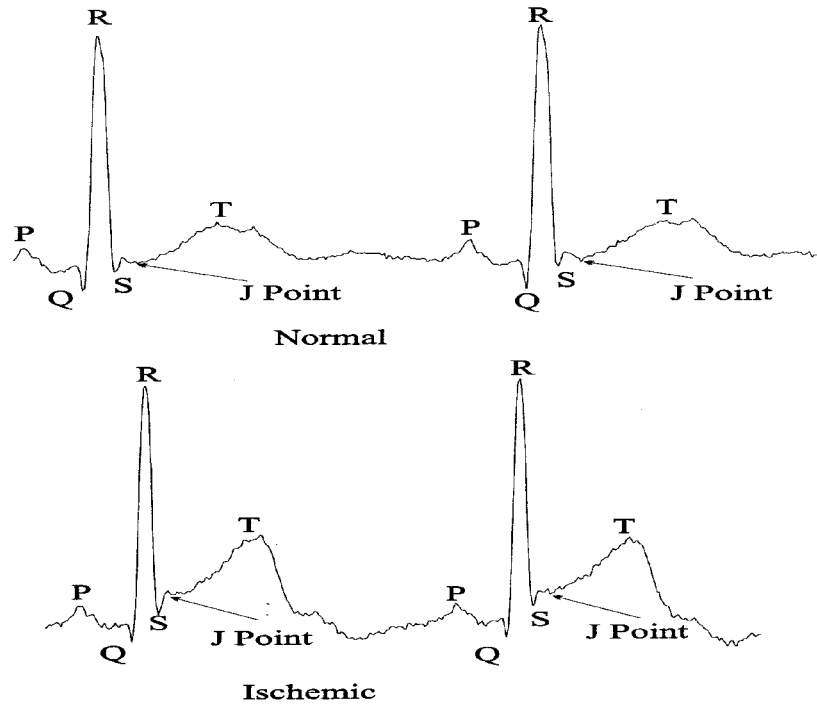


Figure 2.1: Normal and abnormal ECG patterns.

In the normal case, we observe the constituent ECG waves and the J point. In the ischemic ECG, we observe the ST elevation (this can be depression also), and we observe in the second beat that the J point is not easily discernible. Also, observe the similarities between the QRS and PVC. The evaluation of all methods dealing with biomedical signal processing is based on standard annotated databases, available worldwide and forming a common reference. The database used for ischemia detection is the European ST-T database while for arrhythmia classification the MIT-BIH database can be used. Especially for the performance evaluation of ischemic beats and ischemic episodes specialized performance indices are often used [11].

2.1.1 Performance Measure Indices—Examples

Usually ECG pattern analysis algorithms are tested on annotated databases, such as the MIT-BIH arrhythmia database, the CSE database, and the European ST-T database. For the case of QRS: PVC classification and of other arrhythmia detection, normal confusion tables or ROC curves can be used for the assessment of each algorithm. For the case of ischemia detection and analysis, the performance of the algorithms is usually measured following the protocol used by Jager et al . More specifically, two sets of performance indices are defined: (1) Sensitivity and positive predictivity for ischemic ST episode detection; and (2) sensitivity and positive predictivity for ischemia duration. Correctly detected episodes are termed true positive (TP) episodes. Their duration is denoted by ISTP. Missed episodes are termed false negatives (FN) and their duration is denoted by ISFN. Erroneously detected no ischemic episodes are termed false positives (FP) with their duration denoted by ISFP. Finally, correctly identified normal beats are termed true negative (TN). Thus, the four indices used are defined as follows:

- 1) Ischemic ST episode sensitivity (ST Se) is the ratio of the number of detected episodes matching the database annotations to the number of annotated ischemia episodes. This index expresses the sensitivity of the algorithm to the identification of ST episodes.

$$(ST\ Se = TP / TP + FN)$$

- 2) Ischemic ST episode predictivity (ST + P) is the ratio of the number of correctly detected (matching) episodes to the number of episodes detected

$$(ST + P = TP / TP + FP)$$

- 3) This index is a measure of the inclination to incur false detection. Here the denominator is the number of ischemic ST episodes detected by the detection algorithm. (3) Ischemia duration sensitivity (IS Se) is the ratio of the duration of true matched ischemia to the total duration of annotated ischemia in the database.

$$(IS\ Se = ISTP / ISTP + ISFN)$$

- 4) Ischemia duration predictivity (IS + P) is the ratio of the duration of true matched ischemia to the total duration of the ischemia detected by the algorithm used

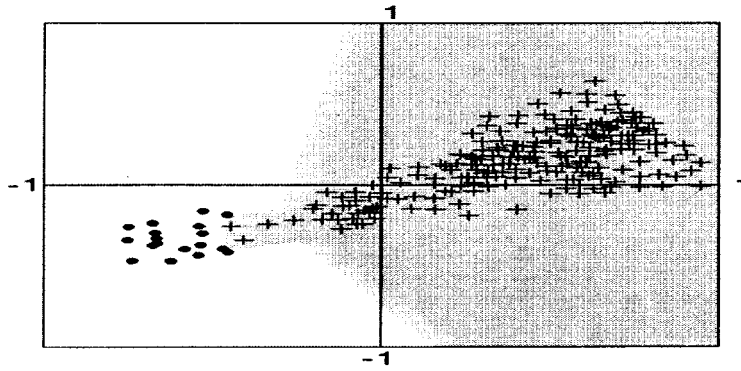
$$(IS + P = ISTP / ISTP + ISFNP)$$

Average statistics are obtained by evaluating the above indices for each file of the database separately, and averaging over the number of files or patient cases.

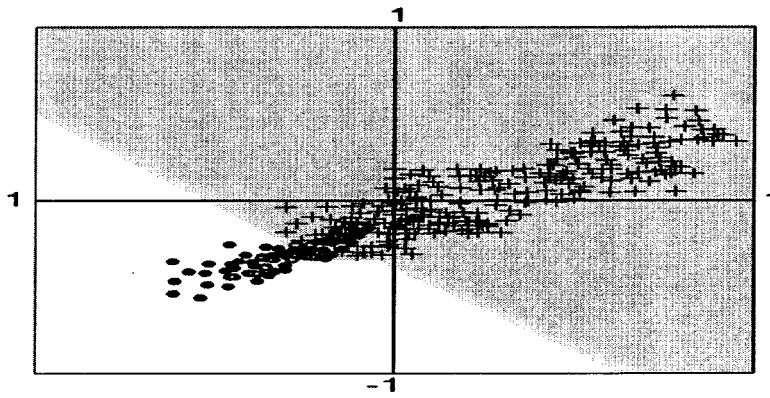
2.1.2 Some Examples of Processing and Classification

Fig. 2.2 shows examples of two files from the MIT-BIH database (103 and 111) where we can observe atrial fibrillation and the QRS: PVC classification problems. The non-linear mapping method used can produce distinct clusters of the normal (depicted by crosses) and abnormal beats (depicted by dots), in the 2-D mapping space as is the case of the data in file 103 (Fig. 4, upper panel). Then, using only ten points as training set, we can draw the separation line using the generating-shrinking NN algorithm described earlier.

For this particular case the separation of the two classes is performed with a 100% success rate. The training and recall phases are extremely fast, and can be performed on each patient's data, ensuring the better performance of the algorithm. Problems might occur when normal and abnormal patterns in the 2-D space are mixed as is the case with file 111. Even in these cases however the generating-shrinking NN performs very well, as can be seen, with high performance indices (91% sensitivity and 82% specificity for the case of this particular file).



MIT-BIH File 103 Atrial vs Normal



MIT-BIH File 111 PVC vs Normal

Figure 2.2: Two different classification examples from the MIT-BIH database.

Namely a trial fibrillation (file 103, upper panel) and QRS: PVC (file 111, lower panel). Observe the high sensitivity and specificity indices in these two cases, especially in the case of file 103 where separation between the two classes is done with 100% success. In file 111 there are some overlapping points, but still sensitivity and specificity for PCV detection stand at 91 and 82% [11].

2.2 ECG classification on BP Neuron Network

Automatic detection and classification of rhythms in electrocardiogram signals play an important role in diagnosis and treatment of critically ill patients. Due to the large number of patients in ICU and the need for continuous observation, numerous methods for cardiac arrhythmias classification have been proposed. In fact, even small improvements to the reliability of such algorithms will save a lot of lives. Ventricular tachycardia (VT) and

ventricular fibrillation (VF) are life-threatening cardiac arrhythmias. Irreversible brain damage may occur in two or three minutes if a shakable rhythm is not treated.

So quick and reliable automatic detection and classification of these arrhythmias are crucial for physician to diagnose the cardiac diseases. Various techniques for ECG arrhythmia classification have been proposed such as knowledge-based systems with statistical methods, time sequenced adaptive filter analysis [12], total least squares-based Prony modeling algorithm [13], complexity measures. But most of them are difficult to compute and implement.

2.2.1 Methods

The data in the analysis and classification was obtained from MIT-BIH database. The NSR and PVC from the MIT-BIH arrhythmias database were sampled at 360Hz, the VT and VF from the MIT-BIH ventricular arrhythmia database were sampled at 250Hz. Two hundred segments each from NSR, PVC, VT and VF were included in the data set. The ECG signals in the current study were re-sampled in order that all the data used in the analysis had a sampling frequency of 250 Hz. Prior to modeling, the ECG signals used in this study has been filtered to remove the noise including respiration, base line drift and wandering etc. This is a 0.4-Hz notch filter with a linear phase characteristic based on the frequency of 250Hz. The data was then filtered to eliminate the power line interference using a 50-Hz notch filter. In current study, the sample size of the various segments was 1.2 seconds. 0.4 seconds before R peak and 0.8 seconds after R peak were picked for modeling. It is adequate to capture most of the information from a particular cardiac cycle.

2.2.2 Classification and Experimental Results

The SNR was used as criterion to evaluate the performance of the AR model with different model orders. The SNR was calculated to be from 16.73 dB to 28.63 dB. The results show that the SNR decreases initially with the model order P , but remains almost constant for model order greater than or equal three. Thus, an AR model of order four was selected for extracting the features in this research. The ECG features were extracted by applying AR process of order 4 to the ECG signals. The feature n_1 and n_2 were extracted under the AR model of order 4. The modeling results shown that the amplitude distribution of white noise $n(k)$ shown in Figure 2.3, which was a experimental result, was very different for the four classes including NSR, VT, VF and PVC, more importantly, the extract cost will not be added to obtain the

feature n_1 and n_2 . In the current case, the positive value $C=0.25$ was found to be the best selection to obtain good feature n_1 and n_2 . Thus, six-dimensional feature vector consisted of 4 AR coefficients and n_1 and n_2 were used to represent an ECG segment in this research. The AR coefficients as well as n_1 and n_2 were given as inputs to a BPNN for classification. The network contained one hidden layer and three neurons in the output layer and used the gradient descent back propagation algorithm with momentum and adaptive learning rate for learning. The training set consisted of 60 vectors each from NSR, VT, VF and PVC. The classification result was shown in Table 2.1.

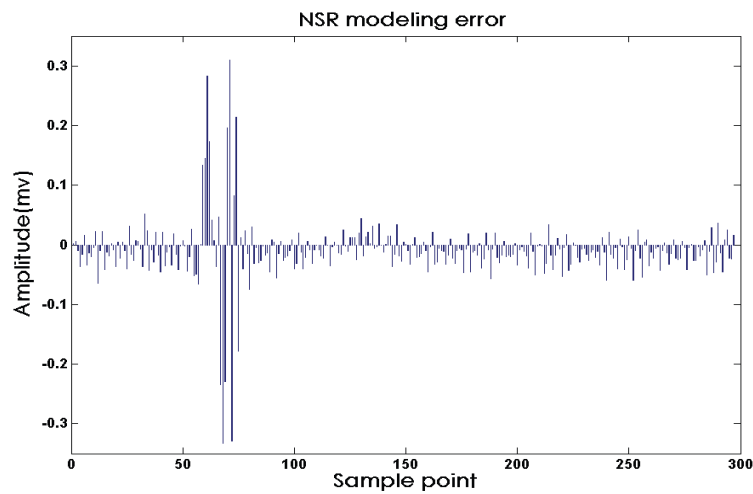


Figure 2.3(a): The distribution of modeling error amplitude

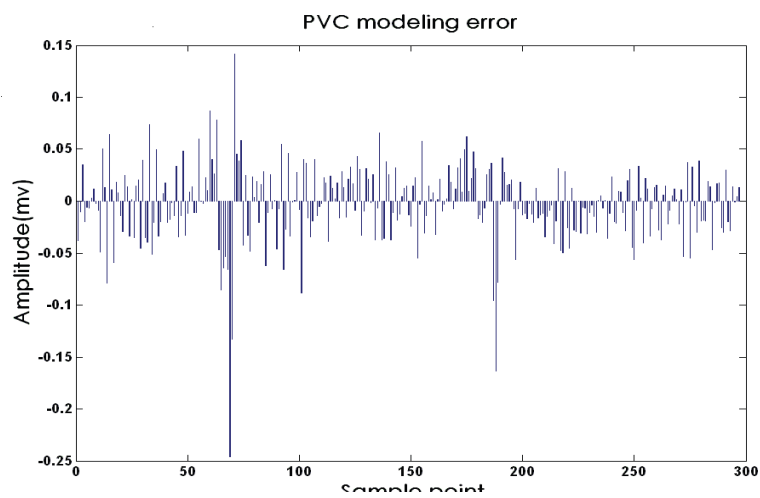


Figure 2.3(b): The distribution of modeling error amplitude

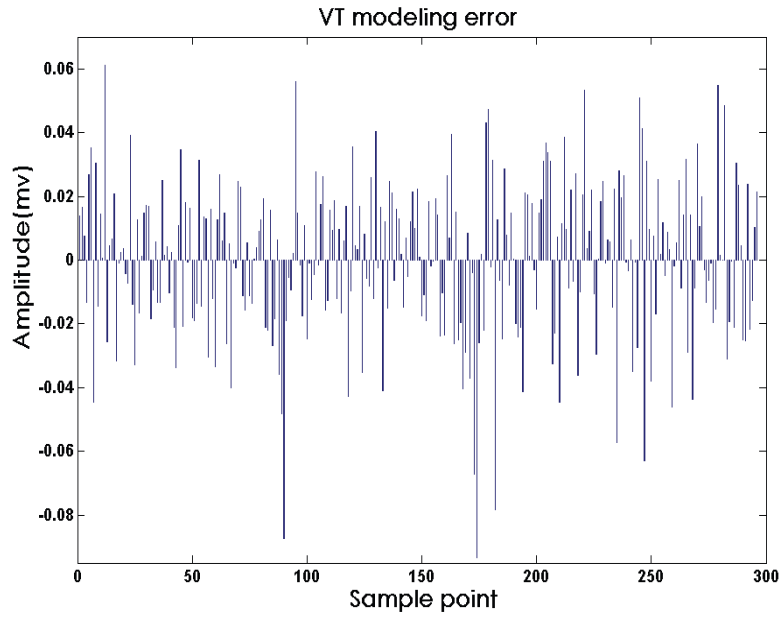


Figure 2.3(c): The distribution of modeling error amplitude

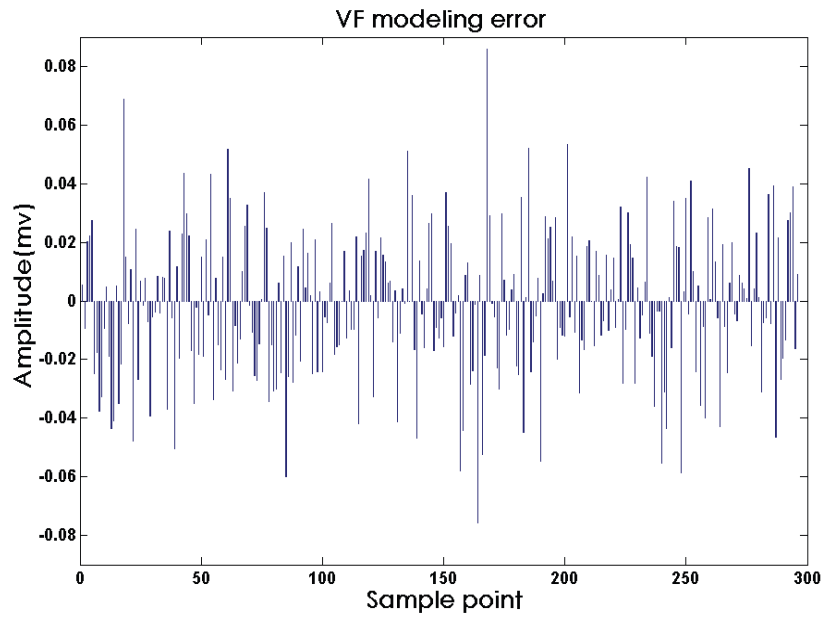


Figure 2.3(d): The distribution of modeling error amplitude

TABLE 2.1: CLASSIFICATION ACCURACY USING BPNN

Classes	NSR	VT	VF	PVC
$(a1, a2, a3, a4)$	96.34%	96.18%	96.18%	95.72%
$(n1, n2, a1, a2, a3, a4)$	95.72%	97.25%	97.11%	96.18%

The simpler AR modeling was performed for the cardiovascular signals of critically ill patients. AR coefficients and $n1$ and $n2$ were used to classify the ECG beats into normal and three different abnormal conditions. Various AR orders were tested for modeling and AR order of four was sufficient to model the beats. AR Coefficients and $n1$ and $n2$ were fed to a feed forward neural network for classification. The classification accuracy is comparable to some of the recently published results on the classification of cardiac arrhythmias.

In addition, AR modeling technique has an advantage to easily compute and Implement than most existing technique. In the current study for AR modeling, a variable sample size based on the estimation of the RR interval might yield better independent of the heart rate of the subjects. AR model is a linear model; It might not be suitable for all ECGs under all conditions because the ECG is not a stationary signal. The generalization capabilities of the AR model and the classification algorithms can be refined by applying the proposed approach to a larger data set. Further work is in progress to extend the proposed approach for classification other types of cardiac arrhythmias as well as applying it to other signals of the cardiovascular system such as the hemodynamic signals, particularly for real-time applications [14].

CHAPTER – THREE

ECG Data Processing and Recording System

3.1 ECG Data Provisioning for Telehomecare Monitoring

Computer and communication technologies applied for acquiring vital signs are promoting novel modalities of patients' health telemonitoring. As a result, nowadays physicians can follow their patients' health condition in real-time and report diseases remotely. Telecardiology, in particular, has developed itself mainly through the acquisition and transmission of electrocardiograms (ECG).

Considering that heart diseases are among the major causes of mortality, this sort of service has called a lot of attention in the last years as an object of research. An example of such initiative in Brazil is the TeleCardio project [15]. TeleCardio is a telehomecare system for remote monitoring of patients with cardiological syndromes. TeleCardio takes advantage of mobile and wireless technologies for the acquisition and transmission of the AECG. The key point is that, when combined with a processing system as far as with those technologies, the AECG allows the diagnosis and/or therapeutic treatment of the myocardial ischemia, an outstanding heart disease that characterizes pre-infarcts. Most of the ischemic episodes take place during daily activities (e.g. physical, emotional) and may lead to a heart attack [16]. TeleCardio system then handles patient's heart monitoring throughout his/her daily activities in order to detect and quantify ischemia episodes at real-time allowing for an efficient emergency rescue. This issue is addressed in TeleCardio by taking into account the concept of context-awareness, i.e., the healthcare applications which use the ECG data must change their behavior in response to modifications in the patient's context. For example, consider the situation where a physician wishes to be notified with a SMS message if his/her patient has an arrhythmia. Besides the emergency support, TeleCardio also aids physician's decision making. Basically, these two features are results of an ECG processing method based on the work of Andreão et al. that carries out a classification on the ECG waveform. Nonetheless, the service

of context-aware AECG data provisioning in real-time for multiple healthcare client applications is still far from a trivial task. There are many challenges regarding both hardware and software such as mobility for the patient, ECG data representation, minimizing the delay in real-time ECG data delivery, designing for reuse and so on. In order to tackle these issues, in TeleCardio project we have applied a domain engineering approach for developing ECG Wrapper, one of its major components. ECG Wrapper is an integrated TeleCardio sub-system (hardware plus software) committed to ECG data acquisition, processing, wrapping and delivery in real-time.

3.1.1 The ECG Wrapper Architecture

The ECG Wrapper has a layered design, which means that its internal functions are hierarchically organized. Each layer interacts only with adjacent layers, providing services to the upper layer by building upon the services from the lower layer. Indeed, this architecture is an instantiation of the Context Wrapper [17], a generic sensor data provisioning system also developed in the TeleCardio project. The architecture is composed by the following entities (see Figure 3.1):

- ◆ Sensors Communication layer (SC): receives the ECG signal from the recording device by a communication protocol.
- ◆ Data Processing layer (DP): carries out ECG data automatic processing to analyze the signal in view of alarm generation and decision support;
- ◆ Graphical User Interface (GUI): allows user (the patient or a health agent) to insert patient's personal data and/or electronic patient record (EPR) obtained from anamnesis as well as for recording session parameters configuration;
- ◆ Wrapping layer (WP): encapsulates the ECG data units came from DP layer as well as the data obtained from the GUI entity into a feasible format;
- ◆ Delivery layer (DV): makes the ECG data available on the web for delivering to health end-user applications and holds subscriptions for the TeleCardio's middleware to take advantage of the services it provides. The Sensor Device (SD) and Data Consumer (DC) entities interact with ECG Wrapper entities at their boundaries to supply and consume ECG data, respectively. These

interactions, as much as the internal interactions, take place at service access points (SAP) through service primitives.

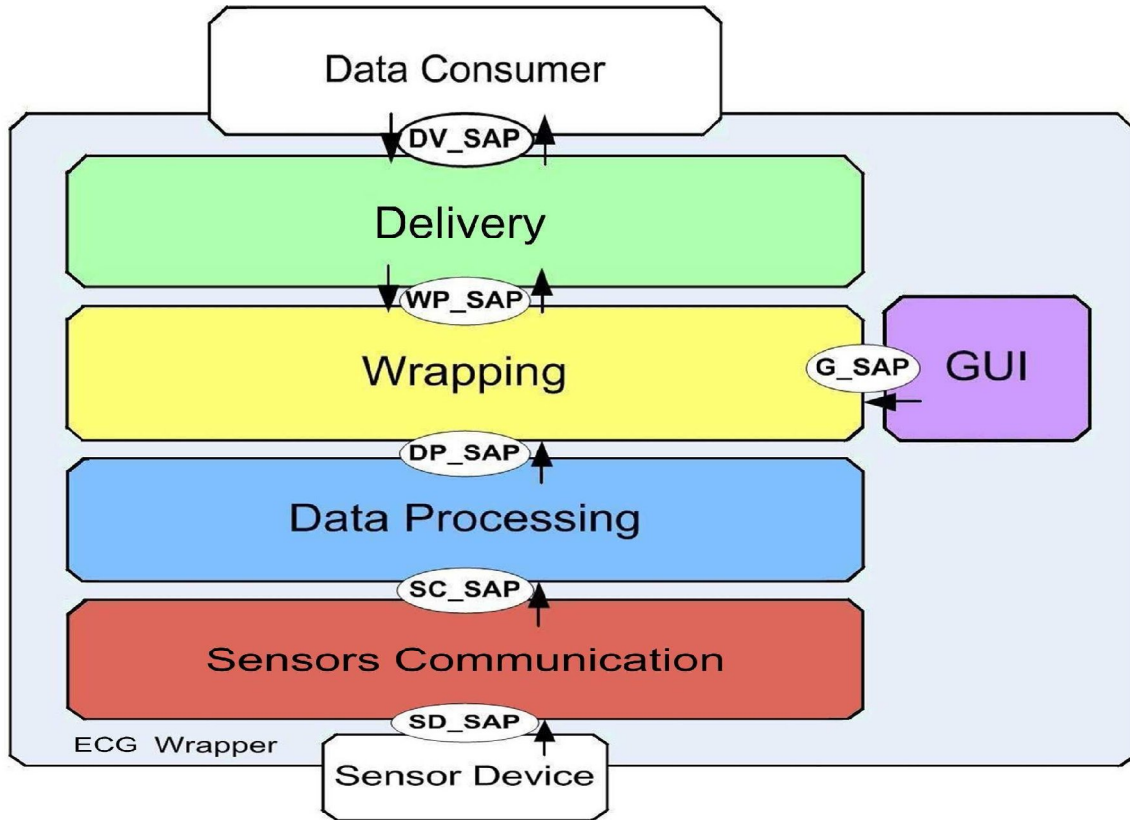


Figure 3.1: The ECG Wrapper Architecture.

3.1.2 Experiments

The ECG Wrapper has been implemented in the context of the TeleCardio project. Concerning distances of up to 20 meters with physical obstructions, i.e., over the walls, we verified a rate close to 100% of successful communications carried out at a bit rate of 115,2 kbps. Increasing the distance to 30 meters, however, the successful rate has decreased to nearly 40% at the same bit rate.

The ECG analysis system of the DP layer has been already validated on standard databases and the results are presented elsewhere in [18]. The results above are among the best results already published using the selected databases. With regard to the WP and DV layers, the delivery of ECG data units (i.e., ECG Aware XML files) to the application server has been successful validated. The ECG waveform acquired by the ECG Wrapper is presented online on

the ECG viewer. Despite we did not precisely measure the time delay, we are aware that the XML ASCII encoding is an inhibitor to make this data transmission faster.

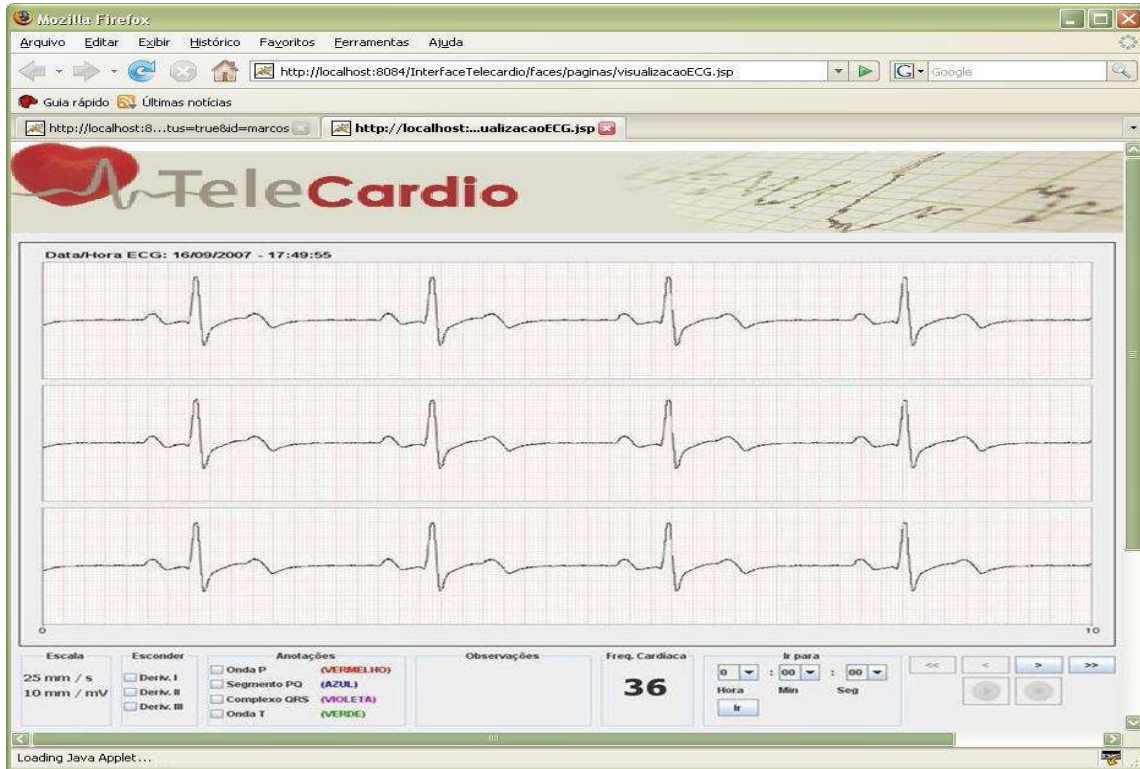


Figure 3.2: Snapshot of the TeleCardio's ECG viewer.

The real-time visualization of the ECG data transmitted from the ECG Wrapper to the health application has been validated over testing either using the ECG simulated data obtained from the Holter device and using ECG records taken from the MIT database [19]

3.2 ECG Signal Recording

Electrocardiography is an important tool in diagnosing the condition of the heart. The electrocardiogram (ECG) signal is the recording of the bioelectrical activities of the cardiac system. It provides valuable information about the functional aspects of the heart and cardiovascular system. Early detection of heart diseases/abnormalities can prolong life and enhance the quality of living through appropriate treatment. Therefore, numerous research and work analyzing the ECG signals have been reported. Naturally, the possibility of the analyst missing (or misreading) vital information is high. Therefore, computer-based analysis and

classification of diseases can be very helpful in diagnostics. Conventional methods of monitoring and diagnosing electrocardiographic changes rely on detecting the presence of particular signal features by a human observer. Due to large number of patients in intensive care units and the need for continuous observation of such conditions, several techniques for automated electrocardiographic changes detection have been developed in the past 10 years to attempt to solve this problem [20].

3.2.1 Features of Some ECG Recording

The appearances in the first recording (Fig. 3.3) were originally thought to indicate atrial tachycardia. Manifestly, this is not the case, for 3 clear reasons. First of all, the rate of the (spurious) P waves is not regular, and regularity of the atrial activation waves would be expected in atrial tachycardia. Secondly, inspection of the deflection just before the second QRS complex in aVL shows that the terminal part of the spurious deflection overlaps the early part of the true P wave (as revealed in that lead in Fig. 3.4). This feature can also be seen in V2 and V3. Finally, the appearances in lead III of the first record show the same rhythm with the same P-wave configuration as in the second record. The deflections giving rise to the suggestion of atrial tachycardia are clearly artifactual and seem most likely to have been produced by instability at the electrode-skin interface (although no confirmation of this is available, and the authors have no means of knowing whether or not, between the recordings, any change of electrode contact occurred or was effected). Inspection of all 12 leads shows that everything is consistent with an artifact at the right arm connection. Note that lead III (which is given by $EF - EL$, where EF refers to the potential at the left leg [“foot”] connection, and EL refers to the potential at the left arm connection) looks exactly the same in both records.

This demonstrates that there is no faulty contact in the left leg (foot) or left arm connections. The fault clearly lies in the right arm connection, and aVR has an almost regular artifact. An artifact produced at the right arm connection will inevitably be visible in lead I (which is given by $EL - ER$, where ER refers to the potential at the right arm connection) and in lead II (given by $EF - ER$). It will obviously also show in aVR (which is given by $ER - [EL + EF]/2$).

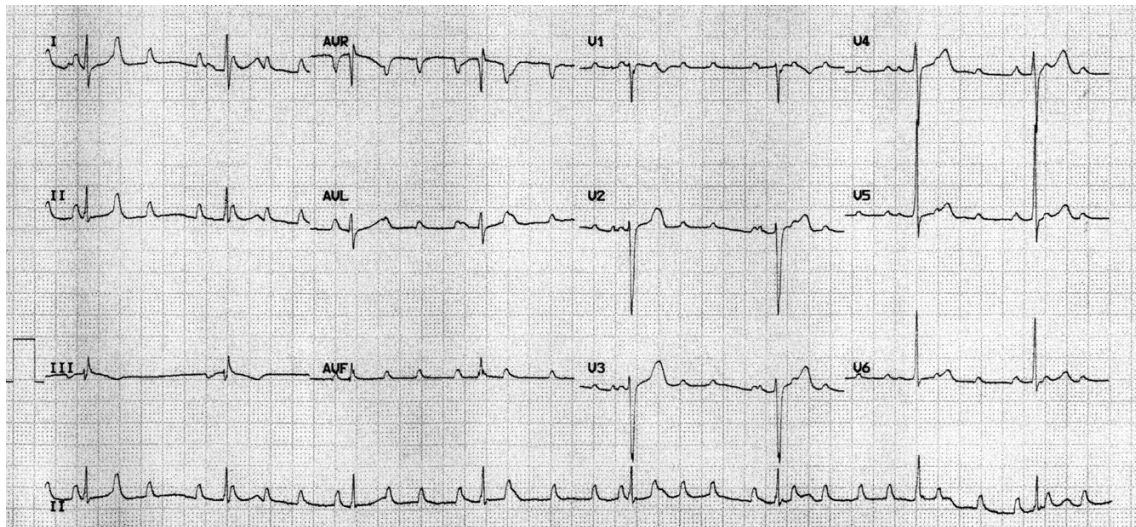


Figure 3.3: The first ECG Recording of a trial tachycardia.

The questions which arise are the following: (i) why does it also show in aVL and aVF (when there clearly is no fault in the connections at the left arm and the foot), (ii) why does it appear in the precordial leads, and (iii) why is the artifact smaller in all these leads? The answers to all 3 questions lie in the fact that these are all unipolar leads, which use the “indifferent connection”. The artifact in these leads arises as a result of the contribution of R to that indifferent connection, and the magnitude of the artifact in each of these unipolar leads is predictable from the composition of the connections to the indifferent lead. Originally (from the historical viewpoint) leads R, L, and F were joined together to form the indifferent connection, which therefore had a mean potential of $(E_R + E_L + E_F)/3$. The original lead VR, therefore, expressed the difference in potential between E_R and $(E_R + E_L + E_F)/3$.

Subsequently, the augmented limb leads were created by omitting from the indifferent connection that limb lead that forms the exploring lead.

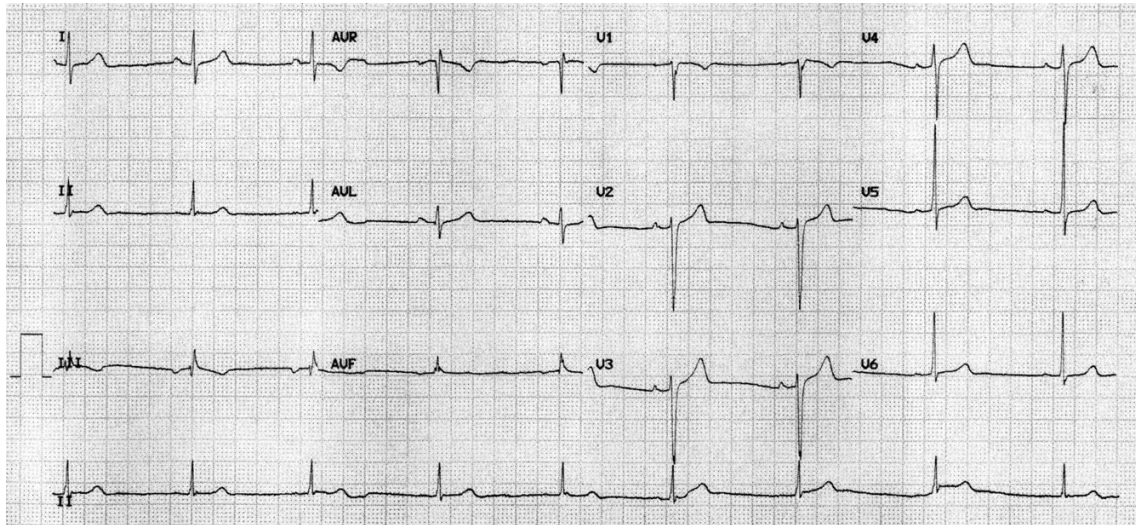


Figure 3.4: This record was taken only moments after that seen in Figure 3.3.

Thus, whereas lead VR displays the potential difference between ER and $(ER + EL + EF)/3$, aVR displays the potential difference between ER and $(EL + EF)/2$. It follows from this that the artifact in aVR will be the same size as that in I and II, whereas the artifact in aVL and aVF will be half the size of the artifact in the bipolar limb leads. This is predictable from the composition of the bipolar and unipolar leads.

$$I = EL - ER:$$

The artifact is in ER and is therefore full-sized.

$$II = EF - ER:$$

The artifact is in ER and is therefore full-sized:

$$aVR = ER - (EL + EF)/2:$$

The artifact is in ER and is therefore full-sized:

However,

$$aVL = EL - (ER + EF)/2:$$

The artifact is in ER and is therefore halved and

$$aVF = EF - (ER + EL)/2:$$

The artifact is in ER and is therefore halved:

Lead III will show no artifact.

$$III = EF - EL:$$

The artifact is in ER and is therefore not apparent in III: The precordial leads, also being unipolar and also using the indifferent connection, show similar but even smaller artifacts to

those seen in aVL and aVF. Lead V1 records the potential at the V1 exploring position (EV1) against the mean potential at the indifferent electrode. Thus,

$$V1 = EV1 - (ER + EL + EF)/3:$$

Thus, the artifact in V1 will be one third the size of that at the right arm electrode, and the same will be true in respect of all the precordial leads. Any artifact produced solely at the right arm connection will give similar-sized artifacts in simultaneously recorded leads aVR, I, and II; half-sized artifacts in simultaneously recorded leads aVL and aVF; and one third-sized artifacts in simultaneously recorded precordial leads. Lead III will show no artifact. Similarly, one would predict that an artifact produced solely at the left arm connection would give similar sized artifacts in simultaneously recorded leads aVL, I, and III; half-sized artifacts in simultaneously recorded leads aVR and aVF; and one third-sized artifacts in simultaneously recorded precordial leads. Lead II would show no artifact. In the same way, an artifact produced solely at the foot connection would give similar-sized artifacts in simultaneously recorded leads aVF, II, and III; half-sized artifacts in simultaneously recorded leads aVR and aVL; and one third-sized artifacts in simultaneously recorded precordial leads. Lead I would show no artifact [21].

CHAPTER – FOUR

STATE OF THE ART

The previous and the following chapters outline the state of the art concerning the applications and Methods used for printing ECG signal in the field of medicine. I have already discussed 12-lead ECG signal & their recording from some examines of the projects technicians from some literature.

In this chapter, history of Electrocardiography will be described and the next chapter presents some estimates already used on printing and signing ECG signals in Java and MATLAB applications on mobile devices, which carried out by statistical methods, and effects on the routine work of doctors. Later, the Chapter carried the main research for our study to work on Printing ECG leads in PDF signal.

4.1 A Brief History of Electrocardiography

Knowledge of bioelectricity started with the observation by L. Galvani in 1787 that a frog muscle contracted when exposed to an electrical discharging process. Galvani postulated the idea of animal electricity, which was for a long time strongly opposed by Alessandro Volta. Only after the development of sensitive Galvanometers (Nobili in 1825 and others) it was possible to prove that there are charges and currents within the frog itself. Matteucci demonstrated in 1843 that also from the resting heart muscle electrical current could be measured [22]. DuBois-Reymond has investigated these Phenomena in more detail and introduced for the changing current associated with muscle contraction the term “action potential”. An action current on the spontaneous beating heart associated with the systolic shortening of the myocardial fibres has been first observed by Koelliker and Müller [23]. DuBois-Reymond developed - by applying a galvanometer - an instrument capable of delivery of stimulation pulses to muscles and measuring discharge currents in a shortly alternating modus. Because of its “flow slicing” it was called a “rheotome”. In 1878 Engelmann was the

first to present graphically the time course of the variations in electric potential of the frog heart obtained by Bernstein's differential rheotome, a modification of the DuBois-Reymond instrument. The first to record electric potentials associated with the beating heart from the body surface was Augustus Desiree Waller in 1887 - 1888 [24]. Waller carried out his studies using the capillary electrometer invented by the French physicist Gabriel Lippmann in 1873.

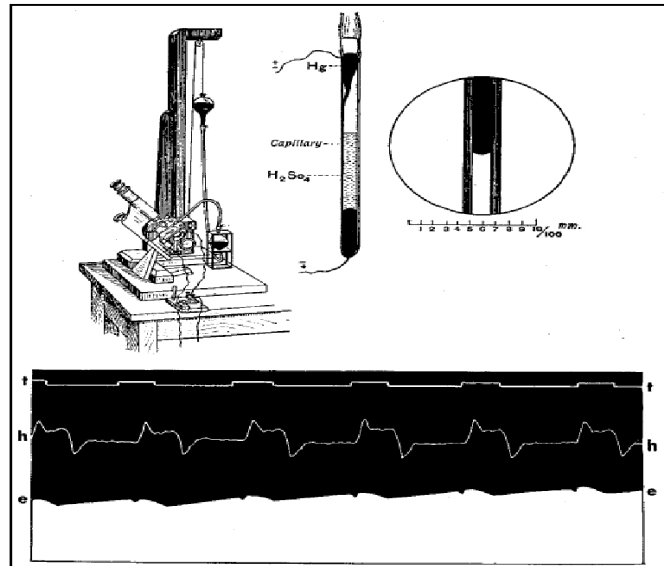


Figure 4.1: the capillary electrometer.

Between 1893 and 1896 George J. Burch and Willem Einthoven developed methods of calibrating and correcting records obtained from the capillary electrometer and predicted finally a signal shape which was close to the “true” ECG shape [25] (see Figure 4.2). Einthoven's denomination of electrocardiographic waveforms is in use until today.

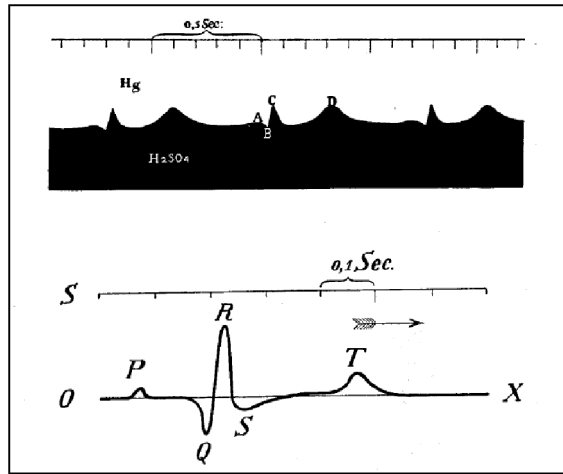


Figure 4.2: Electrocardiographic notation suggested by Einthoven

It deserves our unrestricted admiration that and how these scientists (without the tools of modern systems theory) predicted the ECG signal just by “thinking” before its shape has been confirmed so brilliantly by the next generation of electrical measurement instruments.

4.2 ECG Recording with Amplified Signals

After invention of the vacuum tube the small electrical signals from the heart could be amplified and the less sensitive, but more rugged, mirror galvanometer came into use. Already in 1928 Ernestine and Levine report in the American Heart Journal the use of vacuum tubes to amplify the electrocardiogram instead of the mechanical amplification of the string galvanometer [26]. In the same year Frank Sanborn’s company converts their table model ECG machine into their first portable version, weighing 50 pounds and powered by a 6 V automobile battery. Very soon the production of portable electrocardiographs started. One of the first amplifier type electrocardiographs in Europe was developed by Siemens and Halske in Germany in 1934 (see Figure 4.3)

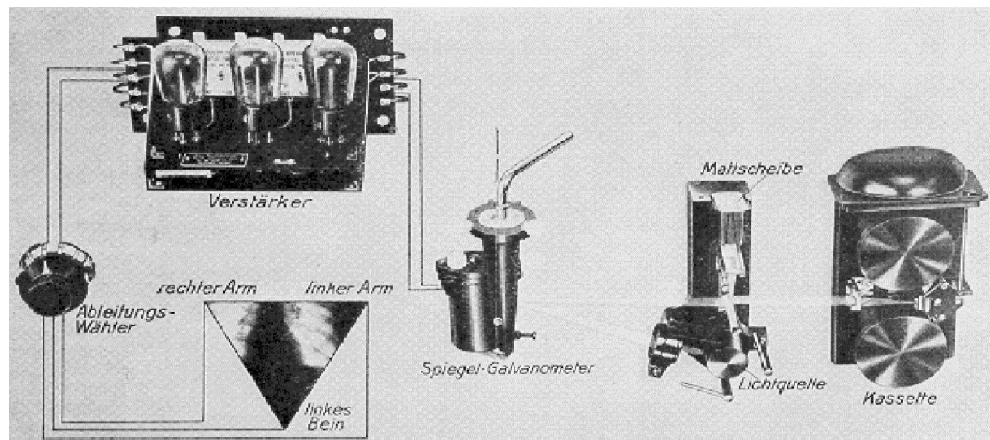


Figure 4.3: Scheme of Electrocardiograph with vacuum-tube amplifier manufactured

Right arm, left arm, and left leg are connected to a lead selector switch. The signal of the selected channel was amplified and fed into a mirror galvanometer. The light beam of this mirror galvanometer was projected onto a ground glass plate and recorded on a film cassette [27]. A further significant step was made after invention of the cathode ray tube. The cathode ray oscilloscope improved considerably the physical characteristics of ECG recording and new avenues for electrocardiographic research, e.g., vectorcardiography, were opened, Hollmann and Hollmann.

A technical breakthrough for wide application of electrocardiography in clinics and at general practitioners was the development of pen-writing (“direct writing”) instruments. A first system was developed by Duchosal and Luthi in Switzerland in 1932. This instrument was produced and marketed by the Hellige Instrument Company. Different principles were used for writing on paper such as the heated pen or the pigment writing system (Fritz Schwarzer Company 1946). The inertia of the pen writing systems has given rise to discussions about the fidelity of the ECG recordings. Therefore the later developed ink-jet writing system by Siemens Elema has reached high acceptance. This system has made possible the paper recording of signals with frequency content up to 800 Hz and the Cardirex ECG portable series of electrocardiographs was very successful on the market.

Later on, with introduction of the computers into electrocardiography write-out systems such as the thermal print head devices and in our days laser printers are replacing all of the conventional ECG recording systems. At this point recording time dependent signals without distortion is not anymore a problem.

4.3 Electrode technology and ECG Recording

So far we have looked at the electrocardiogram as a phenomenon and we have looked at devices for display or recording without consideration of the problems associated with the pick-up of bioelectricity. Figure 4.4 shows a historical illustration how Waller in 1888 picked up the electromotoric forces of the human heart.

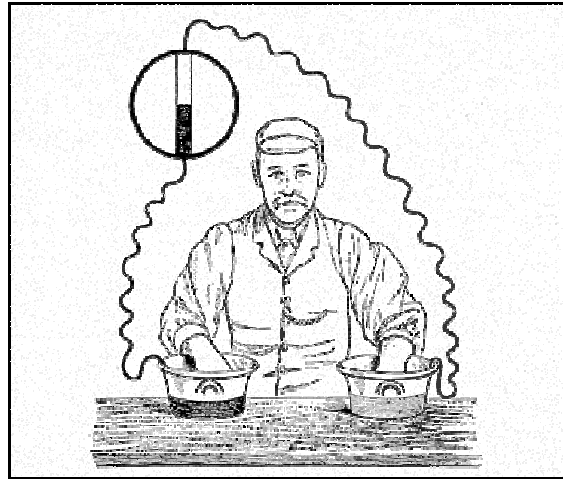


Figure 4.4: Subject connected to the capillary electrometer by means of pan electrodes.

There is a basic difference in generation and representation of electrical signals in biological tissue and metallic conductors. In biological tissue electrical fields are generated by biochemical processes in which ions are separated, concentrated, and moved on account of thermodynamic forces, concentration gradients, or impressed electrical potential gradients. The problem in making electrical measurements from biological tissue is therefore that potential differences to be measured reside in an electrolytic medium while the measurement instruments are connected by metallic wires with electron conduction [28]

The state of art concerns of my study is the printing and signing of ECG signals to PDF format since PDF format is easy to adjust and is very user friendly. PDF format has been chosen because of its flexibility and adjustability. It's very easy to adjust the print layout and the paper configuration as the figures are easily stretchable and adjustable.

CHAPTER – FIVE

Printing and Signing Methods of ECG signal

5.1 ECG paper based printout Principle

The electrocardiogram (ECG) is a vital sign signal for heart functional investigation. This electric signal is generated from human heart for create the cardiac cycle which generate the blood circulation. It composed with three basic components named P wave, QRS complex and T wave as show in (figure 5.1) P wave is generated when atrium depolarization. After that QRS complex is generated when ventricle depolarization and T wave is generated when ventricle recovery. The cardiovascular disease is one of the leading causes of death around the world. While the lacking of physician who is an expert for analysis on ECG signal is one of serious problem especially on rural area also. Therefore the research on ECG classification method for ECG printout is aimed to relieve this problem. The example of paper based ECG printout is depicted in figure 5.1.

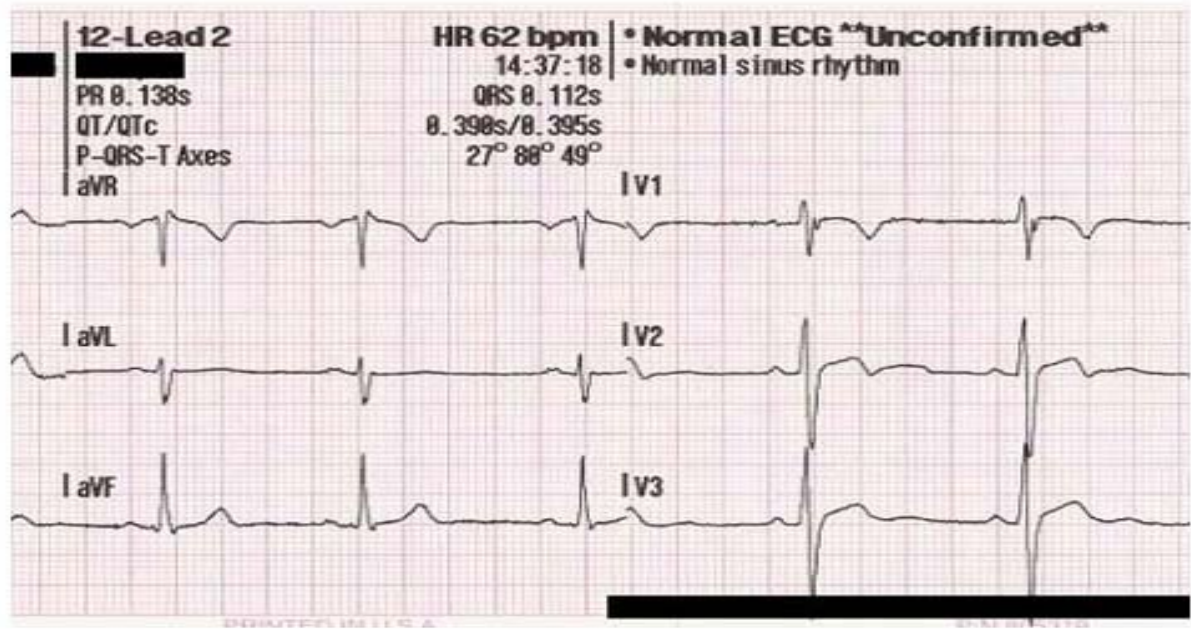


Figure 5.1: Example image of paper based ECG printout .

5.1.1 ECG beat detection from ECG printout

This section is dedicated for ECG beat retrieval method from ECG printout.

I. ECG Paper Scanning

The image is scanned with 300 dpi which is equivalent to 295 Hz (3.4 msec/pixel) sampling rate for data recorded with speed of 25 mm/sec.

II. Select Area of Interest

An interesting ECG beat is then selected from the image for image and signal processing.

III. ECG image Binarization

The selected segment of ECG image is loaded as gray scale because the color of ECG signal from the original paper is black and the color of paper grid is red. Threshold selection (130/255) is used for create binary image. But noise will appear in sometimes as shown figure 5.2. Then it needs to eliminate noise after binarizing the image.

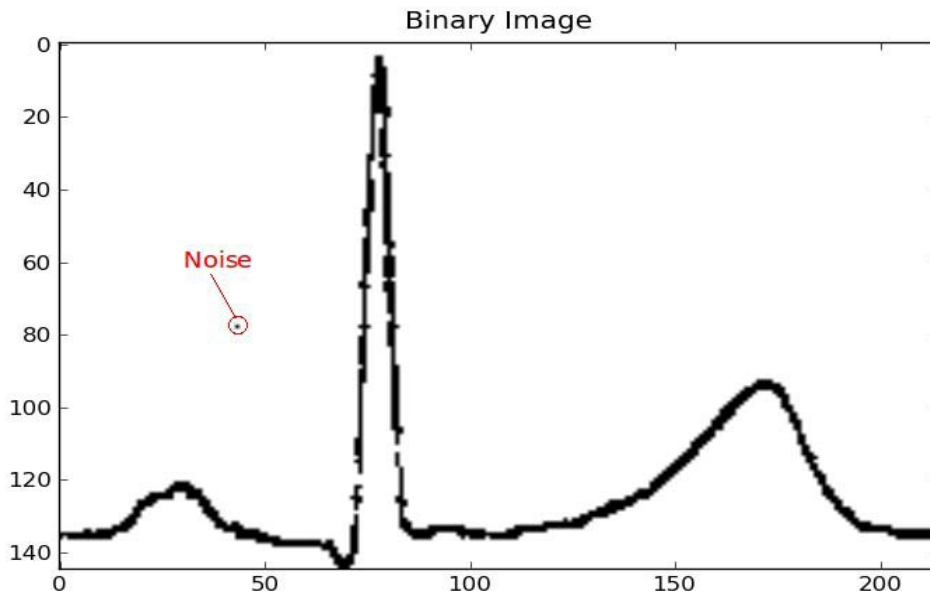


Figure 5.2: Binary image of ECG and noise

IV. Noise rejection

To remove the noise on the image after binarization process, the following process of noise rejection is applied to the binary image. The process starts by scanning vertically to find out the black pixel. If the black pixel is found and all adjacent pixels around it are white background color, then this black pixel will be considered and treated as a noise which will be replaced with white background color.

V. E. Image thinning

Since the line of ECG trace of original scanned image from ECG printout has a thickness which is a redundant of data in time series domain. Then thinning process with moving average algorithm is used to eliminate this redundant of data. Moving average in top-down fashion is used for thinning binary ECG images. When applying 5-point moving average to the binary image after noise rejection, the location of maximum value within 5-point window is used to determine the position of the thinning output pixel. The result of thinning process and noise rejection is shown in figure 16.

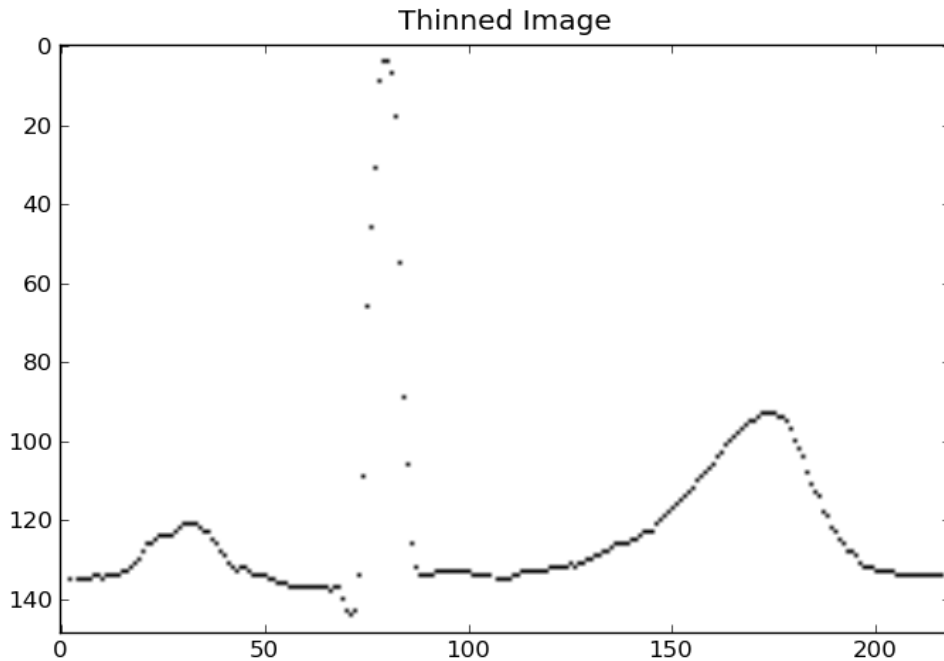


Figure 5.3: Output after thinning and noise rejection

5.2 SVM Training

SVM is a supervised learning method for linear separable data with maximum margin value. There are 4 types of signals: Normal beat, Left bundle branch block beat, Right bundle branch block beat and premature ventricular contraction. Single lead is used for training (MLII or limb lead II).

I. Data Preprocessing

High quality of feature vector will yield the better result of classification. Then data preprocessing is applied for this purpose. Digital filtering is used for eliminate noise on ECG signal. After that Discrete Wavelet Transform and PCA is used for enhance features of filtered ECG signal.

II. ECG Signal Down Sampling

Because ECG signal from MIT-BIH database is sampling at 360 Hz then down sample to 200 Hz is required for compatible with sampling frequency of signal for ECG when implementation. Down sampling factor is 9 and up sampling factor is 5.

III. Digital Filtering and Database Construction

This filter aim to reduce the influence of noise, such as muscle noise, power line and baseline wonder. After filtering, we construct the same size of database for SVM training and evaluation (45686). Each data in new database is compose with its labels for each type of beat annotations such as -1 for Normal, -2 for Left bundle branch block beat, 1 for Right bundle branch block beat and 2 for Premature ventricular contraction [29]. Data in each database is ECG beat with 225 samples where the peak of QRS complex is the 113th sample which normalized and removed DC component.

5.3 XML-Based 12 Lead ECG Structure Report System

It is crucial to develop a computerized 12-lead ECG report that can provide clinicians with interactive ECG waveform measurement and report editing in clinical practice. With the help of computer-assisted ECG waveform measurement, the errors resulting from visual interpretation can be reduced. In addition, an ECG report with the detail description of ECG patterns, cardiologist's interpretation, and treatment strategies will enhance ECG diagnostic efficiency and decrease medical errors. Until now, most clinically-used 12-lead ECG information systems do not provide clinicians with a tool that can interpret ECG waveform and edit ECG report simultaneously. One frequently-used medical informatics standard, Digital Imaging Communications in Medicine (DICOM), has defined various clinically-used structured reports including image- and waveform-based clinical tests [30]. The DICOM structured report is a binary format which is composed of elements with number-based identifiers. The required elements and data types for a structured report are summarized in DICOM part 16. The DICOM structured report enables the link between DICOM-based image and text-based clinical diagnostic information. With the use of DICOM structured reports, clinicians can easily find out the correlations between abnormal images and diseases. Extensible Markup Language (XML) based ECG data formats have been employed on most of clinically-used 12-lead ECGs. Until now, there is not any computerized ECG information system that can enable the link between ECG waveform characteristics and heart diseases. There are several successful applications of DICOM-XML conversion . The XML-based 12-lead ECG report system can be used to improve the efficiency of 12-lead ECG diagnoses.

5.3.1 Methods

The 12-lead ECG DICOM structured report is composed of 12 structured report templates including TID 3700 in the root level, TID 1002, TID 3701, TID 3702, TID 3708, TID 3713, TID 3714, TID 3717, and TID 3719 in the first level, TID 1003, TID 3715, and TID 3718 in the second level. The major function of each template is summarized as below:

- 1) TID 3700: TID 3700 represents the ECG study, which is used for global ECG measurement and waveform information.
- 2) TID 3701: TID 3701 represents the ECG clinical context, which is used to describe the reasons for ECG exam.
- 3) TID 3702: TID 3702 represent prior ECG exam, which is used to link prior ECG records.
- 4) TID 3708: TID 3708 represents ECG acquisition information, which is used to describe the ECG instrument setting such as filter bandwidth.
- 5) TID 3713: TID 3713 represents ECG global measurement, which is used for the references of ECG interpretations such as RR interval, QT interval, and R axis.
- 6) TID 3714: TID 3714 represents the individual ECG measurement, which is used to describe the patterns and measured values of abnormal ECG waveform characteristics.
- 7) TID 3715: TID 3715 represents the ECG measurement source, which is used to indicate the abnormalities of a specific waveform with exact location in the ECG chart.
- 8) TID 3717: TID 3717 represents ECG qualitative analysis, which is used to summarize clinical ECG interpretation.
- 9) TID 3718: TID 3718 represents ECG interpretative statement, which is used to summarize the probability and statement of ECG interpretation.
- 10) TID 3719: TID 3719 represents the summary of ECG, which is used to summarize the finding of this ECG exam.
- 11) TID 1002: TID 1002 represents the observer context.
- 12) TID 1003: TID 1003 represents person observer indentifying attributes.

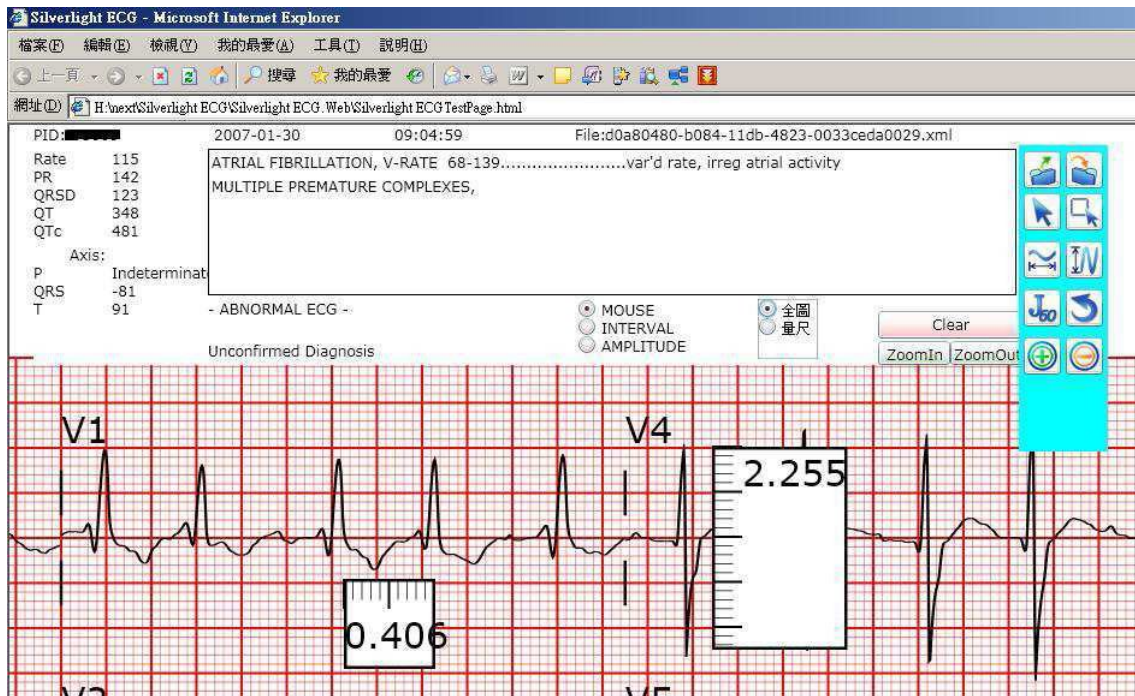


Figure 5.4: The Silverlight-based ECG editor.

A vector graph visualization technology, Silverlight, is employed to display ECG waveform. In addition, a web-based XML ECG editor is developed to provide clinicians with on-line ECG report editing and waveform measurement. As shown in Figure 17, the physicians can summarize ECG interpretation and finding based on the XML schema on the foreground-web directly [31].

The corresponding background-XML ECG file will be changed, and which is followed by the changes of foreground in real time, using XML 12-lead ECG reporting system, clinicians will be able to benefit from ECG waveform pattern search. In addition, clinicians can significantly enhance their ability to find out correlations between ECG characteristics and related heart diseases.

5.4 ECG simulator based on MATLAB Web Figure

In a MATLAB based ECG simulator, which can generate normal lead II ECG wave forms, was designed. In a web-based ECG simulator named The Six Second ECG Simulator was designed and in a simulator named simECG was developed using C++ language. Recently, MATLAB Web technology is a popular tool for the web-based biomedical applications and

learning platforms. Therefore, in the design of WebECG, we have used MATLAB Web Figure and MATLAB Builder NE. By the help of this simulator, ECG signals in the various forms such as normal and arrhythmia can be plotted, long-term ECG signals can be generated, three different noise signals can be added to clear ECG signals and the components of ECG signals can be easily analyzed. An important feature of WebECG is to run with standard server service without the need of any extra software. Users can access the proposed web-based ECG simulator using only a web browser via PC, laptop, PDA or smart phone, etc., connected to the Internet. In WebECG, ECG signals can be showed in 3-dimensional view, and it can be performed zooming and moving on graphics by the help of MATLAB Builder NE and Web Figure technology. Thus, users can analyse the details of ECG signals more easily and visual.

5.4.1 System architecture and design steps of WebECG

System architecture of the WebECG is composed of user and server layers as shown in Fig. 5.5. Server layer receives information from Internet using web browser, process according to user's demands and then displays it. MATLAB Builder NE and .NET technology are used to perform all process in server layer. Therefore, MATLAB is not necessary to be installed in server layer. User layer is responsible to perform connection with server, to select desired features of simulator and to receive displayed ECG graphs by servers. Users can access the ECG simulator using only a web browser without the need of any program. For this reason, the simulator can be used with devices such as laptop, PDA or smart phone connected to the internet. WebECG has been developed using MATLAB Builder NE (MATLAB compiler for NET Platform) [32].

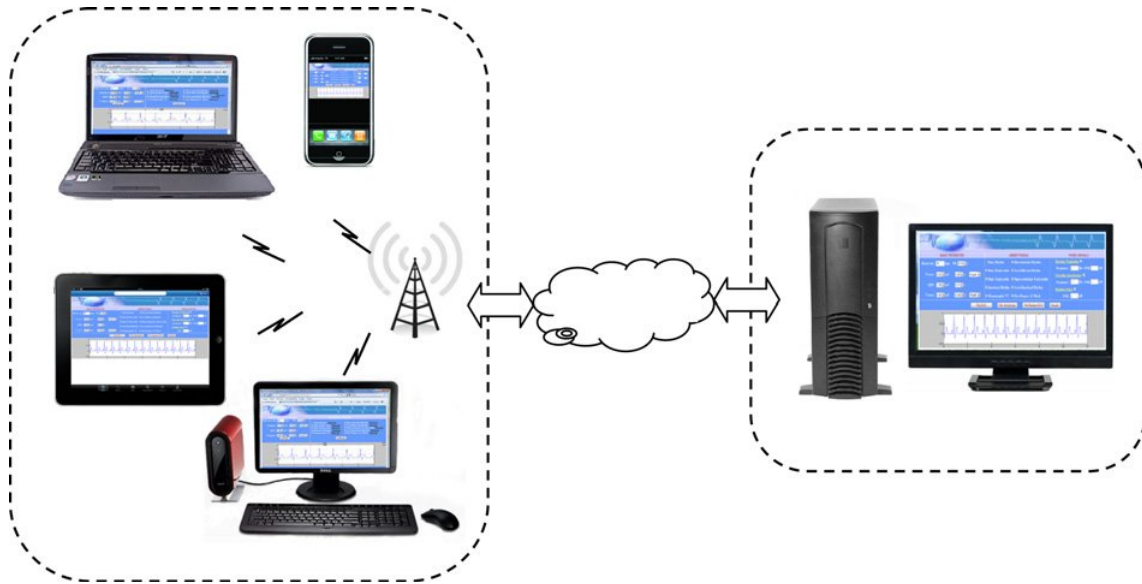


Figure 5.5: System architecture of WebECG.

5.4.2 ECG Signal Recording, Processing and Transmission using a Mobile Phone

Mobile phone is perhaps the most popular device of daily use, which supports sound, text and video applications. Audio, video and text messages can be stored, processed, transported and, most importantly, transmitted from one device to another via Bluetooth, IR, WLAN, USB ports, MMS, GPRS, and Internet. The possibility to capture and store biosignals in multimedia file format is of great importance due to flexibility in storing and transmission of these files by numerous devices. Hitherto, most of the research in biosignal processing through mobile phone concerns transtelephonic transmission via GSM networks [33], wireless ECG capturing, ECG signal processing, remote ECG monitoring and the display of ECG signal on mobile's screen [34]. The ECG signals can be displayed on the screen of physician's mobile phone running Symbian OS or supporting JAVA applications, while sent packed as sound signal from anywhere (patient site) through an ordinary phone line and phone device with the help of small adapter. The received signals can be further stored, analyzed or transmitted elsewhere.

5.5 Materials and Methods

The block diagram of the suggested ECG monitoring system is presented in Figure 19. The transmitting side of the system is composed of an acquisition part (A), which deals with the capturing of ECG signals, a modulator block (B), which transforms and packs the spectra of the captured signals in the frequency band of a standard phone line, and a conditioning circuit, which allows the coupling of the modulator output to the microphone input of the first phone or any kind of hands-free phone accessory connected to it.

Using a JAVA application, the sound signals is digitized, stored and sent as an MMS to the second phone – the one of the physician. With the help of another JAVA application (C), the individual ECG signals can be demodulated and displayed.

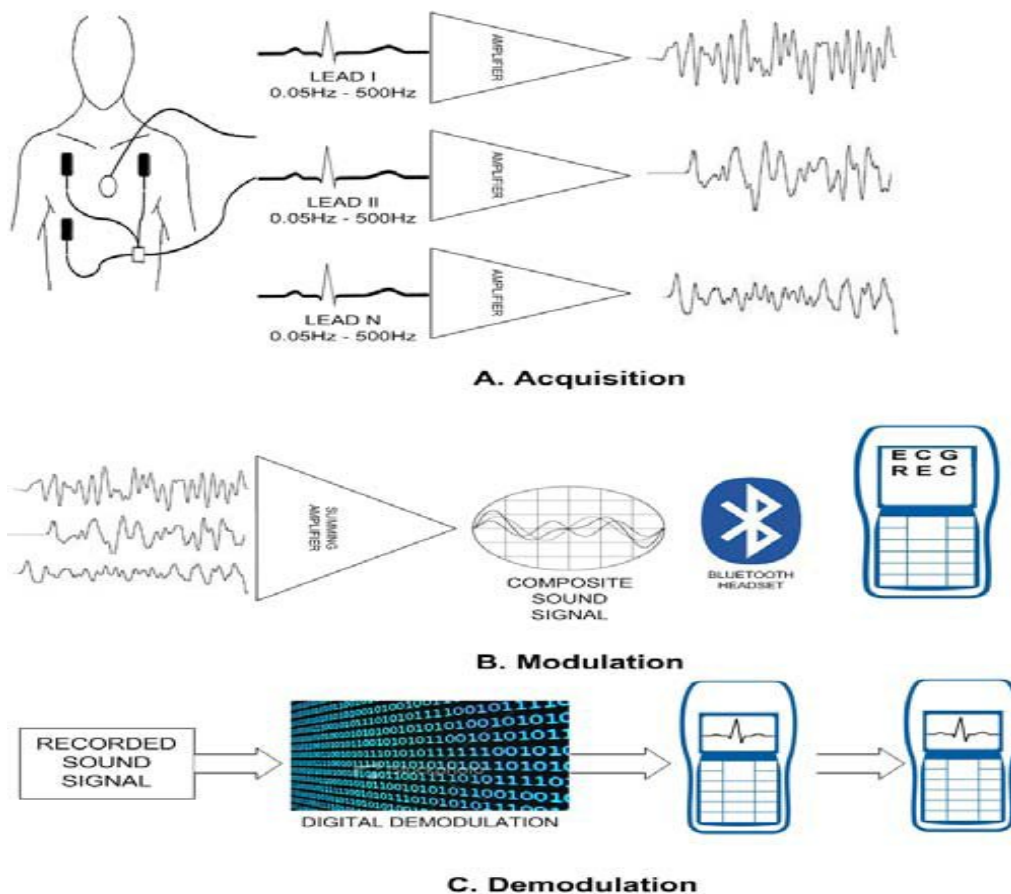


Figure 5.6: Block diagram of a remote ECG monitoring system

5.6 JAVA Applications

An application was designed to work in any mobile phone supporting Java™ (See Figure 20). Two versions – one for professionals and a second for any user were developed. First version refers to physicians and exploits all facilities of the application. Application is initiated with the choice “*Capture a new ECG*” or “*Retrieve*” an already existed ECG from a database that has been built in the application. If the user selects the first option, a signal is recorded in the database. Application also automatically runs a demodulation algorithm and stores every ECG lead, as a separate file in the database. The database is a medical file record containing not only ECGs but also information about patients’ medical history. By storing older ECG in the database, physician is able to retrieve them in order to compare a new ECG with an older one, fact that is very useful in diagnosis.

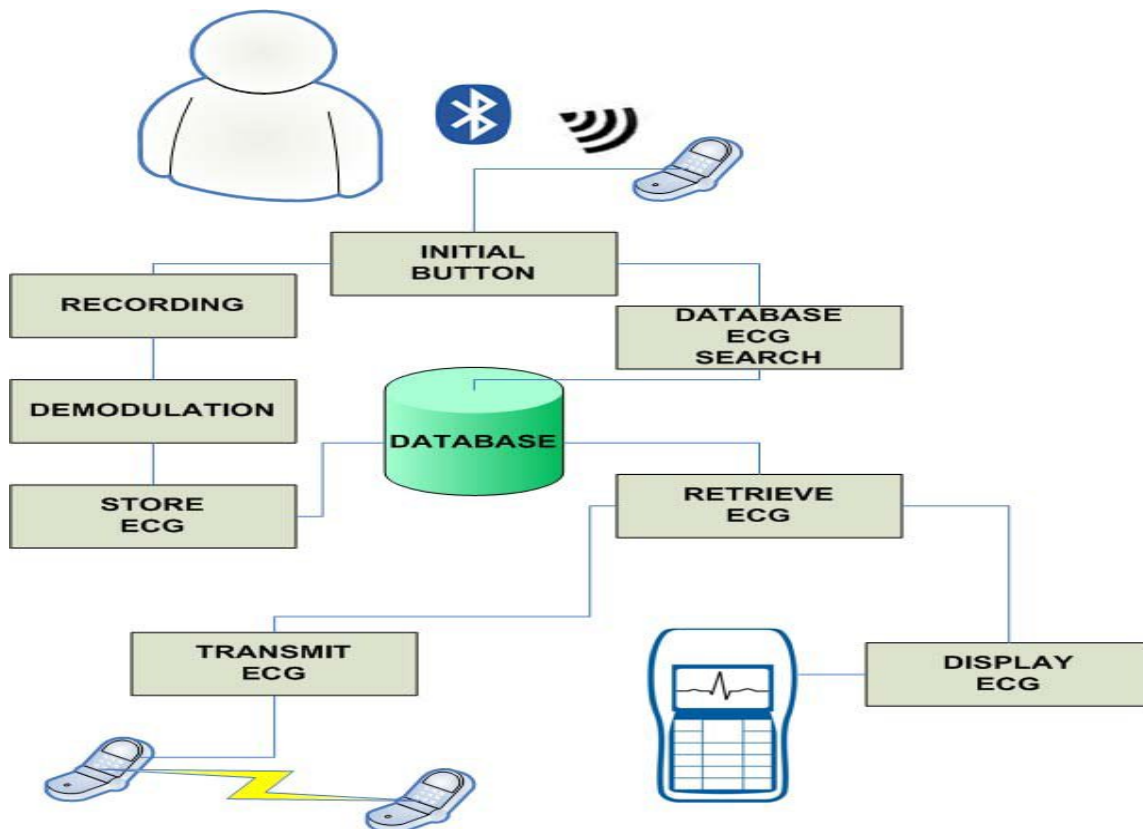


Figure 5.7: Application’s Design

Transmission function gives the capability not only to transmit an ECG from the database but also to choose the way of transmission. Depending on user's choice, ECG is able to be transmitted as any multimedia file- via MMS or GPRS to another mobile phone. Other communication interfaces (Bluetooth, cable connection, IR or WLAN connection) can also be used to transmit the ECG in another local device [35].

CHAPTER – SIX

TOOL USED IN THE STUDY

6.1 Goals of the Thesis

This study is oriented towards printing and signing ECG signal in Portable Document Format (PDF) owing to its importance, because it is a file format used to represent documents in a manner independent of application software, hardware, and operating systems. Each PDF file encapsulates a complete description of a fixed-layout flat document, including the text, fonts, graphics, and other information needed to display it. Some of the research work regarding ECG signals printing and signing in different formats already exist as have been discussed in the previous chapters. This study explores different aspects of presenting it therefore PDF format has been selected for it. Not only being a different format is an advantage but also its easy to use, portability and small file size are some extra ordinary advantages. A PDF file of ECG does not take a few Kilobytes of space in devices both portable and non portable. This application can be a huge use to carrying around ECG files in portable format in mobile phones and tablets.

This is also useful for security purposes as PDF files can be secured very easily and can have a good measure of security over it. The standard security provided by Acrobat PDF consists of two different methods and two different passwords, "user password", which encrypts the file and prevents opening, and "owner password", which specifies operations that should be restricted even when the document is decrypted, which can include: printing, copying text and graphics out of the document, modifying the document, or adding or modifying text notes and AcroForm fields.

6.2 Design Choices

To obtain my goal for study this project printing ECG leads on PDF file we choices the tool java and iText library. iText is a Java library originally created by Bruno Lowagie which allows to create PDF, read PDF and manipulate them. The iText classes are very useful for people who need to generate read-only, platform independent documents containing text, lists, tables and images. The library is especially useful in combination with Java(TM) technology-based Servlets: The look and feel of HTML is browser dependent; with iText and PDF anyone can control exactly how they servlet's output will look.

Java applet is delivered to users in the form of Java bytecode. Java applets can run in a Web browser using a JavaVirtual Machine (JVM), or in Sun's Applet Viewer, a stand-alone tool for testing applets. As browsers have gained support for native hardware accelerated graphics in the form of Canvas and WebGL, as well as Just in Time compiled JavaScript, the speed difference has become less noticeable.

We are describing some medical institute developed database used for ECG signal and their recording system and also our data we used for our project. ECG data we recording 500 samples / second our ECG leads 500 Hz per second.

MIT-BIH

For the validation of the analysis algorithms related to arrhythmias and rhythm abnormalities failure has been used a database of annotated ECG signals, namely the MIT-BIH Arrhythmia Database (27) (28) (29). Completed and distributed since 1980, represents the first standard tool available to evaluate the performance of a software identifier of arrhythmias. It includes a set of records obtained from the Holter Beth Israel Hospital Arrhythmia Laboratory between 1975 and 1979. About 60% of these recordings were obtained from hospital patients. The database consists of 48 ECG records, each containing two signals corresponding to two different branches of the same patient. In addition to samples of each signal and notes of each beat, are also stored in the database information relevant for patients and medicines which they entered. The database contains 23 records (Numbered from 100 to 124 with some numbers missing) chosen randomly from all of the Holter recording and 25 record (from 200 to 234) selected from the same set in order to include a range of rare but clinically significant heart disease. Each record of the 48 has slightly longer than 30 minutes.

AHA (American Heart Association)

The American Heart Association (AHA) developed a database of arrhythmias and normal electrocardiograms (ECG) contained in two series of meticulously-edited, beat-by-beat, annotated recordings. For years, the AHA ECG database recording has been the ultimate measure of accuracy and reliability for evaluating ECG arrhythmia detection equipment. Each recording is three hours long and the beats in the last 30 minutes have been classified. The digitized information includes: 2-channel ECG data at 250 samples/second, 12-bit precision; beat arrhythmia classification data; and timing data.

6.3 System Description

6.3.1 Java Applet Eclipse

An applet is a program written in the Java programming language that can be included in an HTML page, much in the same way an image is included in a page. When you use a Java technology-enabled browser to view a page that contains an applet, the applet's code is transferred to your system and executed by the browser's Java Virtual Machine (JVM). Applets are used to provide interactive features to web applications that cannot be provided by HTML alone. They can capture mouse input and also have controls like buttons or check boxes. In response to the user action an applet can change the provided graphic content.

A Java applet extends the class `java.applet.Applet`, or in the case of a Swing applet, `javax.swing.JApplet`. The class must override methods from the applet class to set up a user interface inside itself (Applet is a descendant of Panel which is a descendant of Container. As applet inherits from container, it has largely the same user interface possibilities as an ordinary Java application, including regions with user specific visualization. The first implementations involved downloading an applet class by class. While classes are small files, there are frequently a lot of them, so applets got a reputation as slow loading components. However, since jars were introduced, an applet is usually delivered as a single file that has a size of the bigger image (hundreds of kilobytes to several megabytes).

6.3.2 Using Java Applet Eclipse

The Eclipse software (26) is an integrated development environment (also referred the acronym IDE, English Integrated Development Environment) multi-language and multi-platform. It is modular and centered on the use of plugins, components Software designed for a specific purpose, and indeed the entire development environment is a set of plugins, including the base version.

Using the Applet Eclipse includes following steps:

◆ **Launching Eclipse**

- ◆ Start Eclipse by running "eclipse.exe" in the Eclipse installed directory.
- ◆ Choose an appropriate directory for your workspace (i.e., where you would like to save your files).
- ◆ If the "welcome" screen shows up, close it by clicking the "close" button.

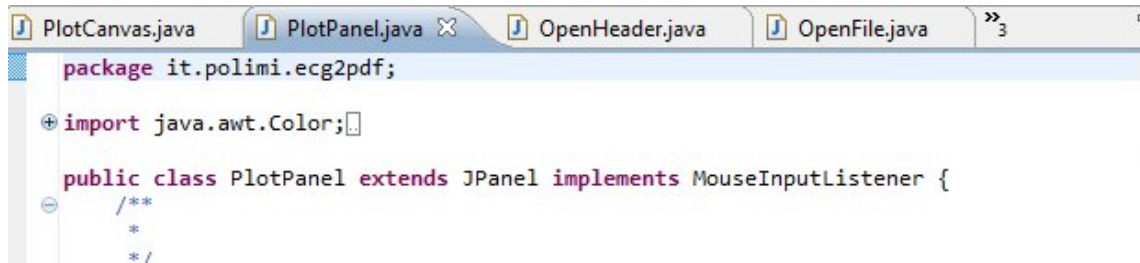
6.3.3 Creating a new Java Project

For each Java application, we need to create a *project* to keep all the source files, classes and relevant resources.

To create a new Java project:

1. Choose "File" menu ⇒ "New" ⇒ "Java project".
2. The "New Java Project" dialog pops up.
 - a) In the "Project name" field, enter "First Project". In this case the name of the project has been given as "ECG DATA".
 - b) Then we have to check "Use default location".
 - c) In the "JRE" box, "Use default JRE (currently 'JDK1.x')" is selected. But the JDK version should be checked, because JDK 1.5 or above should be used.
 - d) After that "Finish" is clicked to finish.

In the following screen shot it can be seen that from the main menu option "Plot panel java" has been selected and sub class package is further chosen to import the data. The data has been imported from the file "ECG data".



```
package it.polimi.ecg2pdf;

import java.awt.Color;

public class PlotPanel extends JPanel implements MouseInputListener {
    /**
     *
     */
}
```

Figure 6.1: Plot canvas Jav

🌀 Java plot canvas

Java Development tool provides many features that allow us to design and build the interface application user. Many of these features are included in the plot graph on java , ECG signal on PDF file which can be accessed by opening in Eclipse one of the layout file of the application. It is divided into the following parts

Our custom graph components require manual drawing, so we use to subclass Canvas, which is the standard component provided for direct graphics manipulation. The technique we're going to use will be to override the paint method of Canvas with the custom drawing that we need. We will use the Graphics object, which is automatically passed into the paint method of

All components, to access colors and drawing methods. We create two custom graphing components: a bar chart and a line graph. We start by building a general framework class for the two graphs, which share some base elements.

6.3.4 Building a Generic Graph Framework

The line graph and bar chart we're going to build are similar enough that we can create a generic Graph class to perform some of the tedious layout work. Once that's done we can then extend the class for the particular kind of graph we need. The first thing to do when we design custom graphics components is to put pen to paper and draw a picture of what we need. Because we are counting pixels, it is easy to get mixed up about the placement of the elements. Putting some thought into the naming and positioning of elements will help us to keep the code cleaner and easier to read later on.

🌀 Our Generic Graph Layout

To create the generic Graph class, we subclass Canvas. The center region is where actual graph data will be displayed; we leave this to an extension of Graph to implement. We implement the other elements -- a title bar, a vertical line to the left, a horizontal line on the bottom, and values for the range -- in the base class. We could specify a font and hard-code the pixel measurements in, but the user would be unable to resize the graph. A better approach is to measure the elements against the *current* size of the component, so that resizing the application will result in a correct resizing of the graph.

Here's our plan: We take a String title, an int minimum value, and an int maximum value in the constructor. These give us all the information we need to lay out the framework. We keep four variables for use in subclasses -- the top, bottom, left, and right values for the borders of the graph drawing region. We use these variables to calculate positioning of graph items later. Let's do a quick look at the Graph class declaration. In following coding we used in our project for drawing ECG signal.

```
public PlotCanvas() {
    this.channels = NEWDataContainer.data.getChannels();
    this.lenght = NEWDataContainer.data.getLength();
    chMax = new int[channels];
    chMin = new int[channels];
    for (int i = 0; i < channels; i++) {
        chMax[i] = NEWDataContainer.data.getMaxVal(i);
        chMin[i] = NEWDataContainer.data.getMinVal(i);
        System.out.println("Max di " + i + " =" + chMax[i] + " Min di " + i
            + " =" + chMin[i]);
    }
    data = new int[channels][lenght];

    for (int i = 0; i < channels; i++) {
        data[i] = NEWDataContainer.data.getSelectedSignal(i);
    }
}
```

Figure 6.2: iText Library

🌀 iText library

iText[®] is a library that allows you to create and manipulate PDF documents. It enables developers looking to enhance web- and other applications with dynamic PDF document generation and/or manipulation. iText allows to read existing pdf's and include them into your own pdf. The requisite tools (Eclipse IDE) and libraries (iText library), we are all set to design and develop to ECG signal to PDF file.

6.3.5 Instantiation of Document Object

Create a PDF document that contains some basic elements like plain text, colored text with non default font, table, list, chapter, section, etc. The purpose of this application is to familiarize the way to use iText library. There are plenty of classes that do lots of work for you related to PDF document generation. It will not be possible to cover all those classes. The javadocs of iText are a good source of information on how to use those classes. The first step is to create a document. A document is the container for all the elements of a PDF document.

```
protected void paintComponent(Graphics g) {  
    shift2Min();  
  
    Document document = new Document(PageSize.A4.rotate());
```

The first argument is the page size. The next arguments are left, right, top, and bottom margins, respectively. The type of this document is not yet defined. It depends on the type of writer we create. For our sample, we choose `com.lowagie.text.pdf.PdfWriter`. Other writers are `HtmlWriter`, `RtfWriter`, `XmlWriter`, and several others. Their names explain their purposes self-sufficiently.

6.4 Results and discussion

In the whole work we used ECG leads for generating a PDF file. The tool used to obtain the solutions is the java and iText library. The ECGs are computed according to the standard 12-lead ECG definition, using the ECG 12-lead definition for our project figure 6.3 and 6.4 contain the calculation.

```

package it.polimi.ecg2pdf;

import java.io.*;

public class OpenFile {
    private String filepath; // percorso del file da cui estrarre i campioni _ path of the file from which to extract samples

    private FileInputStream fi;
    DataInputStream di;

    int raw_data;
    int currSample = 0;
    int currChannel = 0;
    int LI = 0;
    int LII = 0;
    int LIII = 0;
    int aVR = 0;
    int aVL = 0;
    int aVF = 0;

```

Figure 6.3: Screen shot 1 from ECG leads calculation in our project.

```

        NEWDataContainer.data.addElement(currNumber, 7);
        // form_d.append(currNumber+" ");
        minus = false;
    }
    currNumber = 0;
} else if (raw_data == 0x0a) { // Ricevuto una tripletta di dati _ Received a triplet of data
    currChannel = 0;
    LIII = ((LI - LII)); // + 2054
    aVR = (-((LI - LII) / 2)); // + 2065
    aVL = ((LI - (LII / 2))); // + 1035
    aVF = ((LII - (LI / 2))); // + 1035
    NEWDataContainer.data.addElement((short) LIII, 3);
    NEWDataContainer.data.addElement((short) aVR, 4);
    NEWDataContainer.data.addElement((short) aVL, 5);
    NEWDataContainer.data.addElement((short) aVF, 6);
    NEWDataContainer.data.incrementLength();
    currSample++;

```

Figure 6.4: Screen shot 2 from ECG leads calculation in our project.

6.4.1 Java for plotting ECG

Using Java plot canvas we plotting ECG leads on PDF file for our project. Java plot canvas allowed us to design and building different interface application for user. Our custom graph components require manual drawing, so we use to subclass Canvas, which is the standard component provided for direct graphics manipulation. The technique we used for to override the paint method of Canvas with the custom drawing that we need. We already used the Graphics object, which is automatically passed into the paint method of all components, to access colors and drawing methods.

```
PlotCanvas.java ✕
package it.polimi.ecg2pdf;

import java.awt.*;

public class PlotCanvas extends JPanel {
    /**
     *
     */
    private static final long serialVersionUID = -8695667408383853834L;

    private int channels;
    private int lenght;
    private int[] chMax;
    private int[] chMin;
    private int[][] data;

    final int PAD = 15;

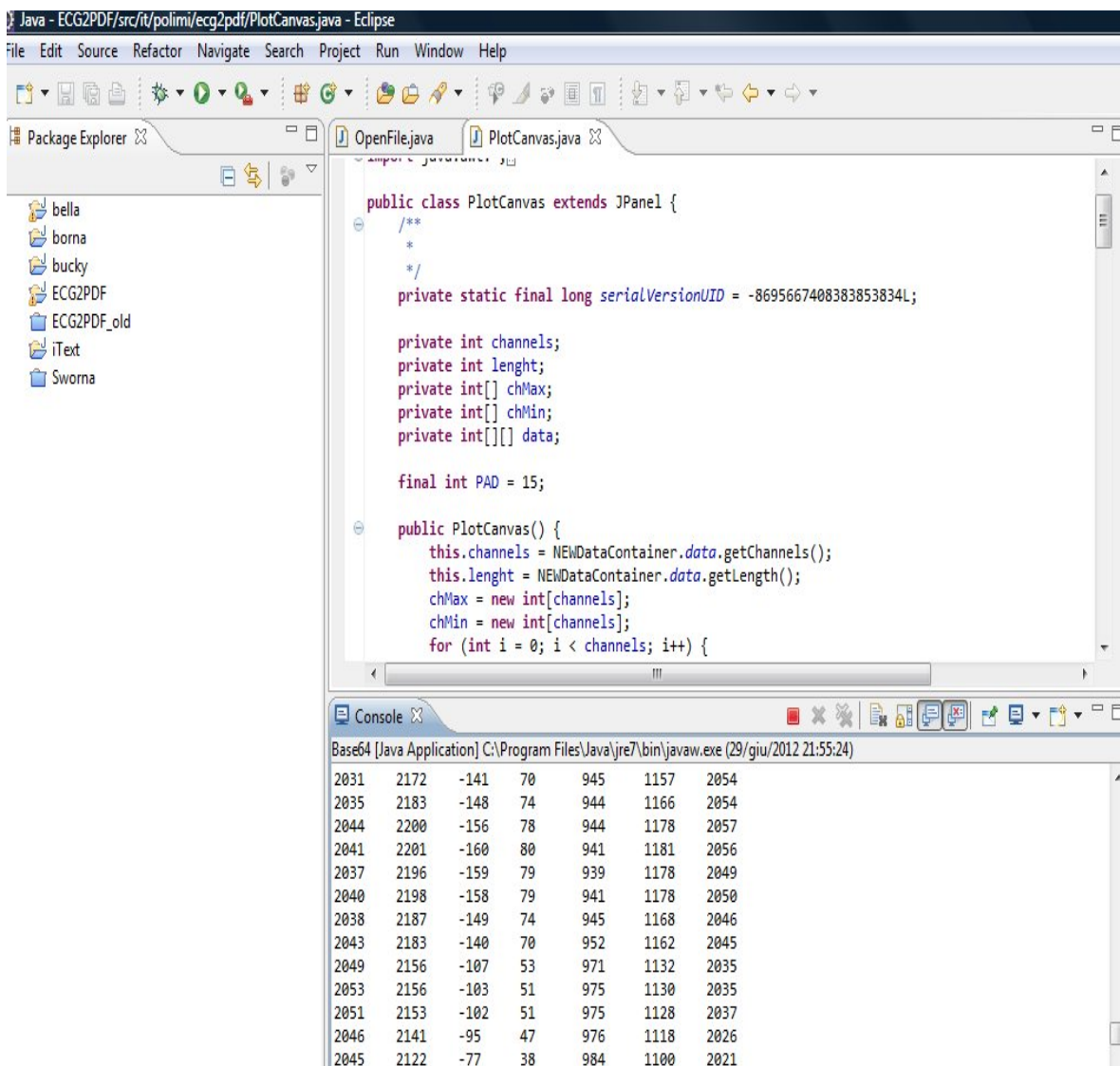
    public PlotCanvas() {
        this.channels = NEWDataContainer.data.getChannels();
        this.lenght = NEWDataContainer.data.getLength();
        chMax = new int[channels];
        chMin = new int[channels];
        for (int i = 0; i < channels; i++) {
            chMax[i] = NEWDataContainer.data.getMaxVal(i);
            chMin[i] = NEWDataContainer.data.getMinVal(i);
            System.out.println("Max di " + i + " = " + chMax[i] + " Min di " + i
                + " = " + chMin[i]);
        }
        data = new int[channels][lenght];

        for (int i = 0; i < channels; i++) {
            data[i] = NEWDataContainer.data.getSelectedSignal(i);
        }
    }
}
```

Figure 6.5: Screen shot 3 from ECG signal plotting on java plot canvas.

6.4.2 ECG Leads on PDF File

The main goal of our project for printing and signing ECG Leads in PDF file we used tool Java and iText library. iText[®] library allows us to create and manipulate PDF documents. In our work we think about printout ECG signal on PDF file cause each PDF file encapsulates a complete description of a fixed-layout flat document, including the text, fonts, graphics, and other information needed to display it and This application can be a huge use to carrying around ECG files in portable format in mobile phones and tablets. The main output from our calculation using ECG –leads showing figure 6.7 and 6.8.



The screenshot shows the Eclipse IDE with the following components:

- Package Explorer:** Lists folders: bella, borna, bucky, ECG2PDF, ECG2PDF_old, iText, Sworna.
- Editor:** Displays the code for `PlotCanvas.java`. The code defines a class that extends `JPanel` and contains several private fields and a constructor.
- Console:** Shows the output of the program, which is a table of numerical data.

```
public class PlotCanvas extends JPanel {
    /**
     *
     */
    private static final long serialVersionUID = -8695667408383853834L;

    private int channels;
    private int lenght;
    private int[] chMax;
    private int[] chMin;
    private int[][] data;

    final int PAD = 15;

    public PlotCanvas() {
        this.channels = NEWDataContainer.data.getChannels();
        this.lenght = NEWDataContainer.data.getLength();
        chMax = new int[channels];
        chMin = new int[channels];
        for (int i = 0; i < channels; i++) {
```

```
Base64 [Java Application] C:\Program Files\Java\jre7\bin\javaw.exe (29/giu/2012 21:55:24)
2031 2172 -141 70 945 1157 2054
2035 2183 -148 74 944 1166 2054
2044 2200 -156 78 944 1178 2057
2041 2201 -160 80 941 1181 2056
2037 2196 -159 79 939 1178 2049
2040 2198 -158 79 941 1178 2050
2038 2187 -149 74 945 1168 2046
2043 2183 -140 70 952 1162 2045
2049 2156 -107 53 971 1132 2035
2053 2156 -103 51 975 1130 2035
2051 2153 -102 51 975 1128 2037
2046 2141 -95 47 976 1118 2026
2045 2122 -77 38 984 1100 2021
```

Figure 6.6: After finish coding Run the program on eclipse.



Figure 6.7: ECG leads on PDF file using java application.

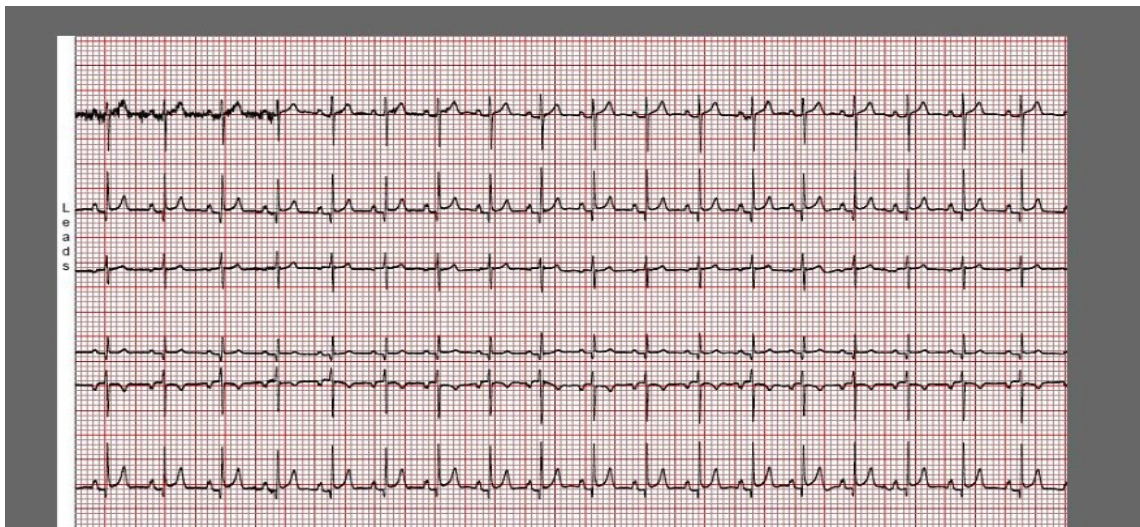


Figure 6.8: Screen shot 4 from PDF file which signing ECG leads.

The most widely used signal in clinical practice is the ECG. It is frequently recorded, and widely used for the assessment of cardiac function. Diagnosis the problem for each patient from ECG printout it is possible to find out their disease. We create some function in our project like, name of patient, Age, sex, weight, date and GMT so in future from medical report for ECG printout it should be easy for diagnosis their previous problem. The coding is shown in figure 6.6 and the output of our result is shown in figure 6.10.

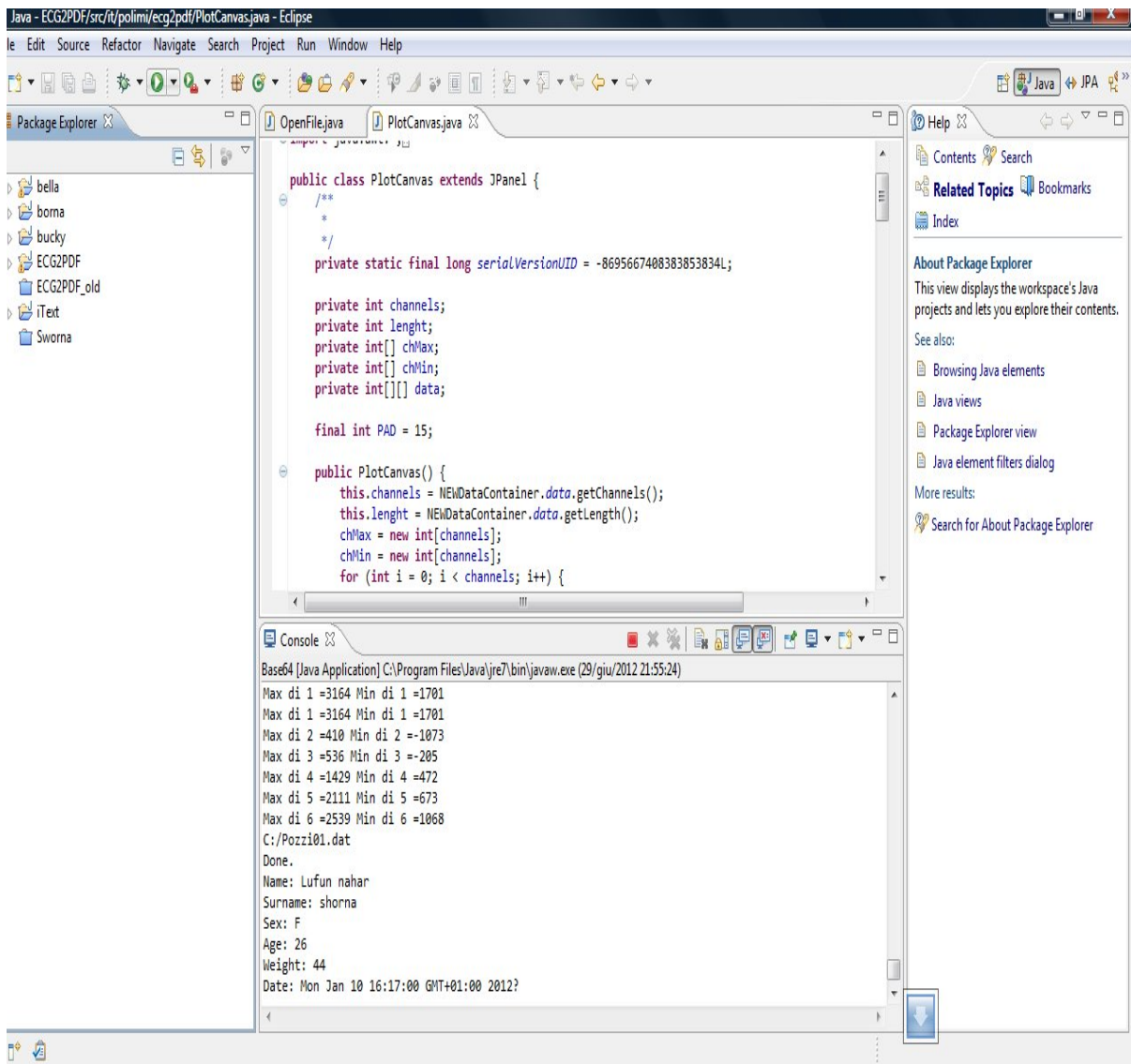


Figure 6.9: Full Screen shot from when run the program on eclipse.

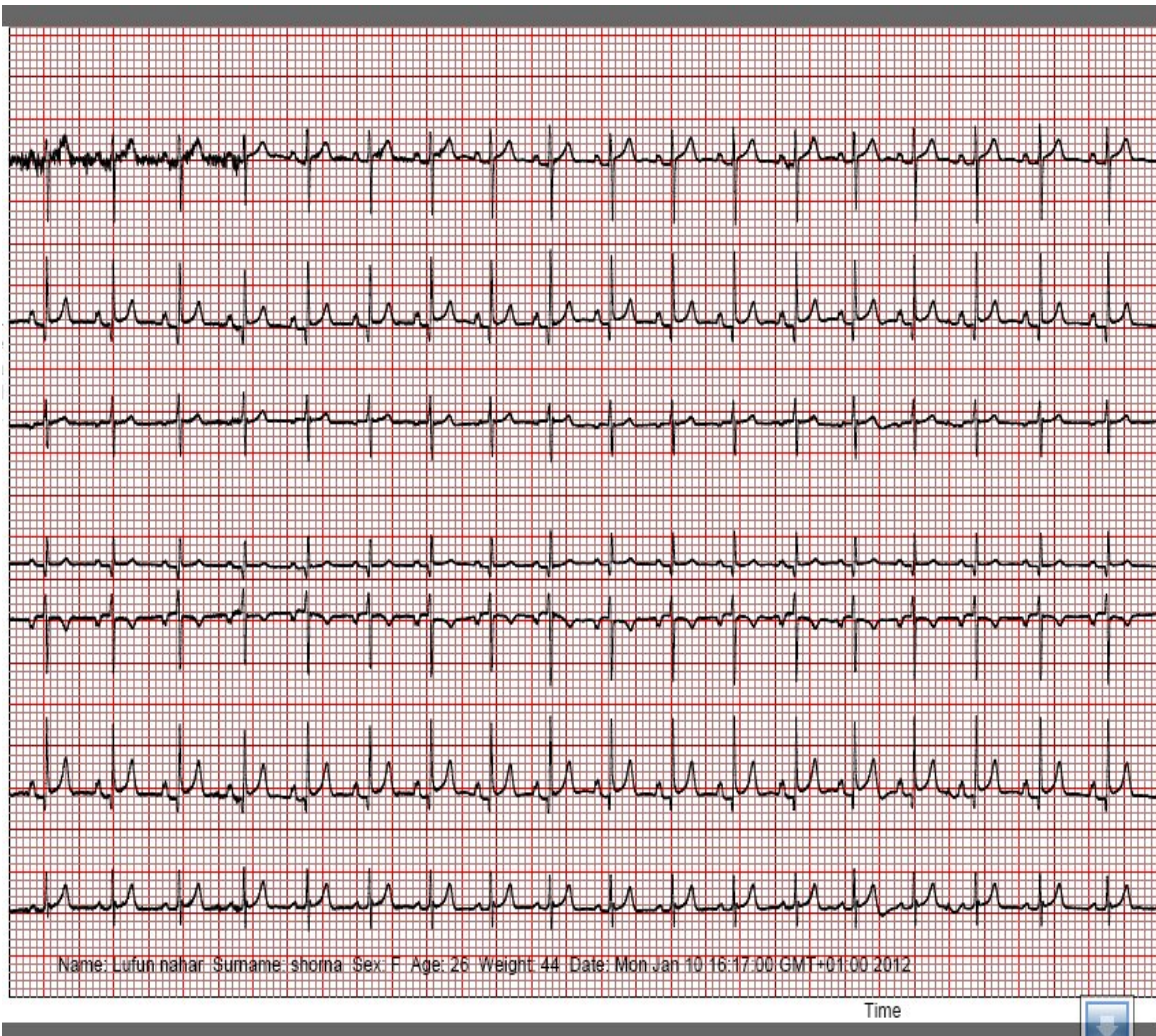


Figure 6.10: Screenshot of our final result ECG signal signing in PDF file.

CHAPTER –SEVEN

CONCLUSION AND RECOMMENDATIONS

This chapter will discuss the conclusion of the study and the simulations carried out in the Software selected for the study which will follow some recommendations related to the future prospects of this work.

7.1 CONCLUSION

Based on the simulation carried out in the Java Applet Eclipse following conclusion can be drawn:

- Eclipse is a user friendly and easy to use software applied to Java Programming and this study proves that the results obtained by this software are accurate and it is capable of carrying out correct simulations.
- This study has focused the use of this Java applet for printing and signing of ECG signals into PDF file and has been found to be useful since this is an important task and needs accuracy and user friendliness being an important part of Medical technology and Databases.
- PDF files are easy to carry around in mobile devices and transfer and storage of such files is not only easy but also secure and reliable.
- Files with data collected from different ECG databases has been run in the software and thus results have been obtained simulating the Algorithms and codes already based on the acquired signal data.

7.2 RECOMMENDATIONS

- ℞ PDF file is undoubtedly very advantageous but at the same time the same advantage serves as its own disadvantage that PDF generally or after being secured is quite difficult to edit which is a nuisance during use. This is a significant constraint of this study.
- ℞ Future study is proposed for further development of the project as there is a great potency of the work for future developments.

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