

ECG Signal Analysis for Detecting Cardiac Hypertrophy using MATLAB

Paridhi Goyal, Maya Datt Joshi, Shaktidev Mukherjee

Abstract: Cardiac Hypertrophy commonly known as abnormal thickening of the heart muscle. It results from the increase in the cardiomyocyte size and other heart muscle component changes, like extracellular matrix. There can be physiological and pathological causes for the cardiac hypertrophy like amount of strenuous physical activity performed by an athlete and hypertension respectively. Most patients today survive hypertrophy, thanks to a number of efficient treatment options. In ECG, the QRS amplitude and duration plays an important role in determination of Cardiac Hypertrophy. Raw ECG data has been obtained from MIT PTB database and analysed using MATLAB. De-noising of the ECG signal has been done using filters. The clinically important parameters for Cardiac Hypertrophy have been evaluated using Fast Walsh Hadamard Transform. Statistical Analysis is done by comparing the parameters thus obtained with those of normal ECG parameters to gain a deeper understanding of Cardiac Hypertrophy. This research in turn can help the physicians to diagnose the preliminary signs of cardiac hypertrophy which might otherwise go un-noticed.

Keywords: Electrocardiogram (ECG), Cardiac Hypertrophy, Hypertrophy, Statistical Analysis, Cardiac Analysis, QRS amplitude, QRS duration, ECG Monitoring, MATLAB, Fast Walsh Hadamard Transform.

I. INTRODUCTION

1.1. Electrocardiogram

An electrocardiogram (ECG) describes the electrical activity of the heart which is measured by the electrodes placed on the surface of the body. The excitable cardiac cells tend to contract other cells thus producing an action potential which is measured by the electrodes as voltage variations. The ECG thus obtained, contains a series of waves depicting the heartbeat morphology and the time duration of the same. This in turn helps in the diagnosis of cardiac diseases which are reflected by the irregular electrical activity of the heart (Hall, 2006).

In 1880s, the first ECG recordings in man were made by Augustus Waller. In early 20th century, Willem Einthoven, a Dutch physiologist, made use of a string galvanometer for recording the electrical potentials on the surface of the body. He also identified the sites on the human body for the placement of electrodes, which are still in use. For his pioneering efforts in the field of cardiology, Einthoven was awarded with Nobel Prize in Medicine in 1924 (Sörnmo, 2006).

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Ever since then, ECG has undergone rapid development and has emerged as the most powerful tool used for assessing the heart health. ECG today is recorded under varied strenuous and diverse medical conditions; all this has been made possible with the development of various signal processing algorithms. Today the ECG wave morphology can be analysed on a beat-to-beat and cardiac micro-potential basis, due to the availability of strong signal processing techniques (Besma Khelil, March 19-22, 2007). The number of electrodes used to record ECG, depends on the type of information which is required. Like if only heart beat rhythm is to be studied, only a few electrodes can be used. On the other hand, if heart beat morphology is to be studied, 10 or more electrodes can be used (Besma Khelil, March 19-22, 2007).

II. HISTORY OF TECHNIQUES USED IN THE ANALYSIS OF ECG

Pipberger and his group in 1956, made preliminary attempts to automate ECG signal analysis. Industrial ECG processing system was developed during seventies. There has been an enormous rise in the development of computer-based programs for analysing ECG over last 15 years. Computers now can act as assistants to cardiologists by monitoring and interpreting an ECG (Pipberger H V, 1990).

Pipberger et al. (1990), in 1956, developed an automatic vectorcardiographic analysis (AVA) program. The software used spatial velocity function for signal recognition. On the basis of QRS-T parameters, the probability of nine alternative diseases was identified using Multivariate Statistical Analysis on orthogonal ECG leads.

Jie Zhou et al. (2003), proposed the Automatic detection of PVC by using Artificial Neural Network i.e. Quantum Neural Network (QNN). MITBIH Arrhythmia Database was used to check the reliability of the fuzzy feature. QNN provides constantly good reliability for accurate diagnosis. Saurabh Pal et al. (2010), proposed a data-based approach to calculate Form Factor (FF) and R peak amplitude in terms of wave morphology and used Artificial Neural Network to classify PVC beats from normal beats. They obtained the sensitivity (Se) 94.11%, specificity (Sp) 97.5%, and accuracy of detection 97.5%.

Anusha F.G. et al. (2015) proposed to use XML ontology to measure ECG sample image for its height and amplitude, in order to determine anomalies. Cardiac predictions of curves are identified using the ontological schema and then the schema is mapped with the input image. Medina Hadjem et al. (2014) proposed Wireless Body Area Networks (WBAN) to be used to detect Cardiovascular Diseases.

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This technique removed the noises from the ECG signal and made use of the Undecimated Wavelet Transform (UWT) to extract nine major ECG diagnosis parameters. Then, Bayesian Network Classifier model is used to classify ECG into four different classes based on the parameters: Normal, Premature Atrial Contraction (PAC), Premature Ventricular Contraction (PVC) and Myocardial Infarction (MI). The experimental results on ECGs from real patients' databases show that the average detection rate (TPR) is 96.1% for an average false alarm rate (FPR) of 1.3%.

Agnes Aruna John et al. (2015), proposed a MATLAB GUI application which made use of the Discrete Wavelet Transform for R-Peak detection. Bayes classifier was also used to classify ECG signals later. The GUI was particularly useful for a non-technical user for analysing the digitised signals.

Hussain A. Jaber AL-Ziarjawe et al. (2015), proposed a method for detecting P,Q,R,S,T values of the ECG signal. The method calculated mathematical relation between the various peaks of the ECG waveform and the time. A MATLAB GUI was developed to draw these peak values on the ECG wave simultaneously.

Jyoti Gupta et al. (2015), proposed use of MATLAB to process the ECG signals acquired from an online ECG database. MATLAB was used for processing the ECG signals. Dijkstra's Algorithm was used to send the processed ECG data from a wireless node to a remote location using a shortest path.

Apoorva Mahajan et al. (2015), proposed the study and analysis of ECG signal by means of MATLAB. The study of ECG signal was done by acquiring real time ECG signals, filtering, processing, feature extraction and analysis of ECG signal. MATLAB is used to process and analyse the data. The developed system is cost effective.

Jaylaxmi C Mannurmath et al. (2014) implemented a simulation tool on MATLAB platform to detect abnormalities in the ECG signal. MIT-BIH Arrhythmia database was used to obtain signals. Pre-processing and feature extraction of the signal is done using Wavelet

toolbox. Classification of arrhythmia is based on basic classification rules.

III. PHYSIOLOGICAL AND ELECTRICAL ACTIVITY OF THE HEART

The human heart is an organ which is of the size of a large fist and it primarily pumps oxygen-rich blood in the whole body. The anatomy of the heart comprises of two "mirrored" sides. The left and right sides of the heart pump the blood in a synchronized and rhythmic manner and in turn support different circulatory systems. The left and the right sides of the heart are further divided into two chambers, Atrium where the blood enters and Ventricle where the blood is pumped into circulation (Jagtap, 2014). Activation and Recovery are two phases of every cardiac cycle, which are also known as Depolarization and Repolarisation.

3.1. Electrical Activity of Heart

The cardiac cycle is initialised in the pacemaker cells of the heart which fire an electrical impulse instantaneously. The pacemaker cells are also known as sinoatrial (SA) node and are present in the upper right atrium. The propagation of the electrical impulse or the electrical wave front takes place through a series of atrial and ventricular contraction and relaxation (as shown in Figure 1). After the left and right atria electrical activation, the atrioventricular (AV) node collects and delays the impulse before it reaches the ventricles (Hall, 2006). This delay helps to increase the volume of the blood in the ventricles through a prolonged atrial contraction, before the ventricular contraction takes place. The delay is the result of low conductivity of the muscle tissue present. Bundle of His, is located between the two ventricles, is a location which connects the atria and the AV node electrically. The electrical impulse enters the bundle of His and then it spans rapidly into various bundles and branches in the left and right ventricles. Further, the impulse spreads across a network of conduction fibres also known as Purkinje Fibres. The impulse propagates rapidly and initiates a unified contraction (Hall, 2006) (Sörnmo, 2006).

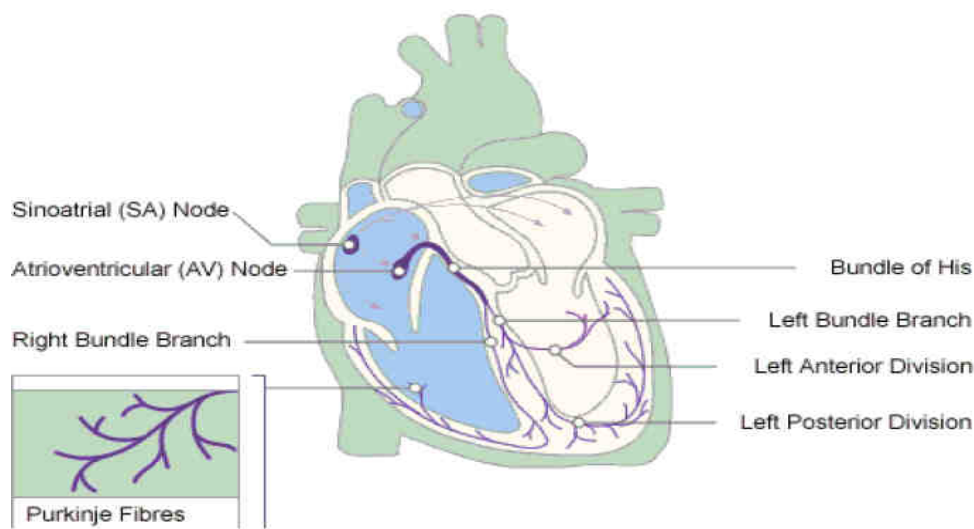


Figure 1. (<https://www.nottingham.ac.uk/nursing/practice/resources/cardiology/function/conduction.php>)

There are four entities of a normal rhythm- P wave, QRS complex, T wave, U wave, each one of which has a unique pattern.

P wave- atrial depolarization

QRS complex- ventricular depolarization

T wave- ventricular repolarization

U wave- papillary muscle repolarization

These patterns exhibit a change with any change in the structure of the heart or its surroundings (Ch.Tanmaya, 2016).

3.2. Clinical Important Parameters

Clinical Important Parameters	Description	Duration
RR-Interval	The interval between an R wave and the next R wave; normal resting heart rate is between 60 and 100 bpm.	0.6 to 1.2s
P-Wave	This is the main electrical vector which is directed from SA to AV node.	80ms
PR-Interval	The interval measured from the start of the P-wave to the start of QRS complex.	120-200ms
PR-Segment	The segment connects the P-wave and the QRS complex. The electrical vector path is AV node to Bundle of His to branches to Purkinje Fibres.	50-120ms
QRS-Complex	Rapid depolarization of right and left ventricles.	80-120ms
ST-Segment	The segment connects QRS complex and the T-wave. It represents ventricular depolarization.	80-120ms
ST-Interval	The interval from the J-point to the end of T-wave.	320ms
QT-Interval	The interval from the start of QRS complex till the end of T-wave.	Upto 420ms

(Anand Kumar Joshi, 2014)

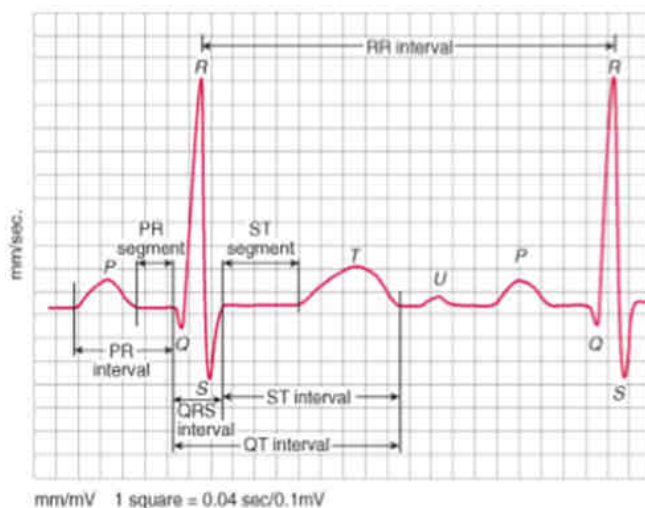


Figure 2. (https://lifeinthefastlane.com/ecg-library/basics/qt_interval/)

IV. CARDIAC HYPERTROPHY

Muscle Hypertrophy is a process where the total muscle mass increases in volume. It is much higher when contractile process increases the load on the muscle. Another type of hypertrophy occurs when the stretch in the muscles is more than the normal value.

The abnormal enlargement or thickening of the heart muscle is known as Cardiac Hypertrophy. It results from the increase in the cardiomyocyte size and other heart muscle component changes, like extracellular matrix. There can be physiological and pathological causes for the cardiac hypertrophy like amount of strenuous physical activity performed by an athlete and hypertension respectively. Left Ventricular Hypertrophy is the result of an increased workload on left ventricle e.g. hypertension. Right Ventricular Hypertrophy is the result of an increased workload on right ventricle e.g. pulmonary embolization. Whereas Hypertrophic Obstructive Cardiomyopathy, is a congenital misalignment of cardiomyocytes.

V. FEATURE EXTRACTION OF ECG SIGNAL

In today's world with the ever-increasing numbers of cardiac patients, it is beyond the capacity of the expert cardiologists to take care of each and every patient efficiently & effectively. Therefore, computer-aided feature extraction and analysis of ECG signal for disease diagnosis has become the necessity. Computer aided diagnosis starts with the identification and extraction of the features of the ECG signal. The detection of QRS complex accurately forms the basis of extraction of other important parameters. Various methods have been used to detect the wave segments of P, QRS, T and there are still others which detect QRS complexes (S. C. Saxena, 1997). Researches have been carried out for establishing a dependable method for QRS detection over the last few decades.

Various Transformative Techniques have been used for QRS detection namely, Fourier Transform, Cosine Transform, Pole-zero Transform, Differentiator Transform, Hilbert Transform and Wavelet Transform. These techniques help in the characterization of the ECG signal into energy, slope, spectra. After this characterization, some decision rules help to identify thresholds of amplitude, slope or duration (D, 1992).

In this research work, MATLAB has been used to process the Raw ECG signals in order to obtain the clinically important parameters, which have been compared with the parameters of normal ECG signal to gain an insight of the cardiac anomaly of MI.

There are various steps in processing an ECG signal through MATLAB:

(1) Real Time Raw ECG Data

The ECG signals have been taken from the MIT PTB DB. The ECG was obtained using 16 input channels (14 for ECGs, 1 for respiration, 1 for line voltage). There are 15 simultaneously measured signals for each ECG record. Each signal is digitized at 1000 samples per second.

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This data thus obtained is in .dat format. It is converted to .Mat format which is readable by MATLAB. Raw ECG Signal Data as obtained from the DB:

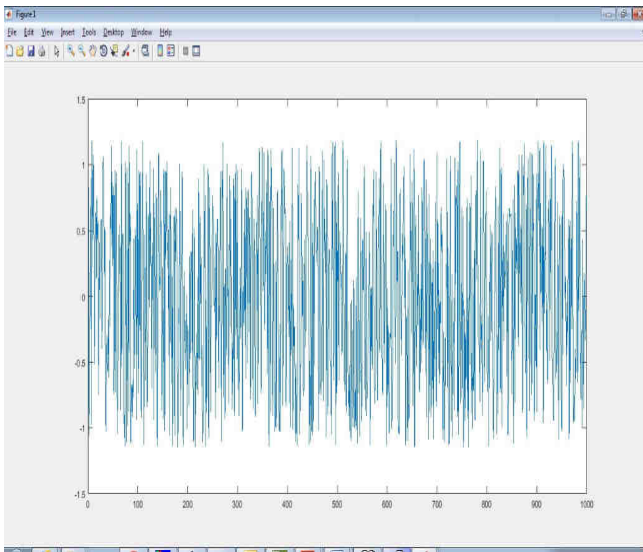


Figure 3: Raw ECG data of Patient 1

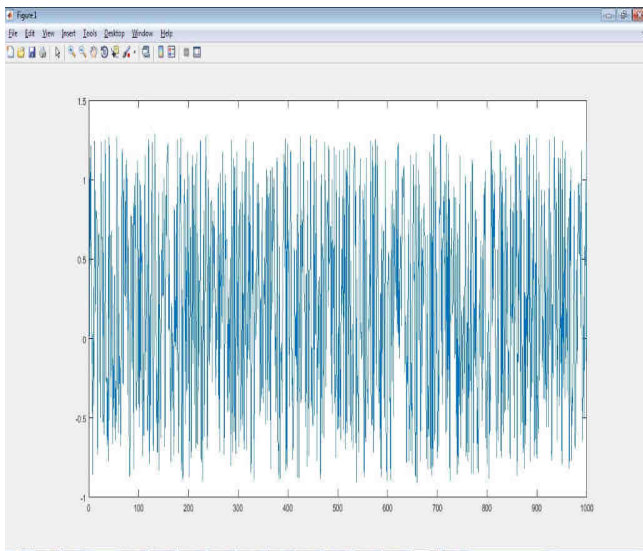


Figure 4: Raw ECG data of Patient 2

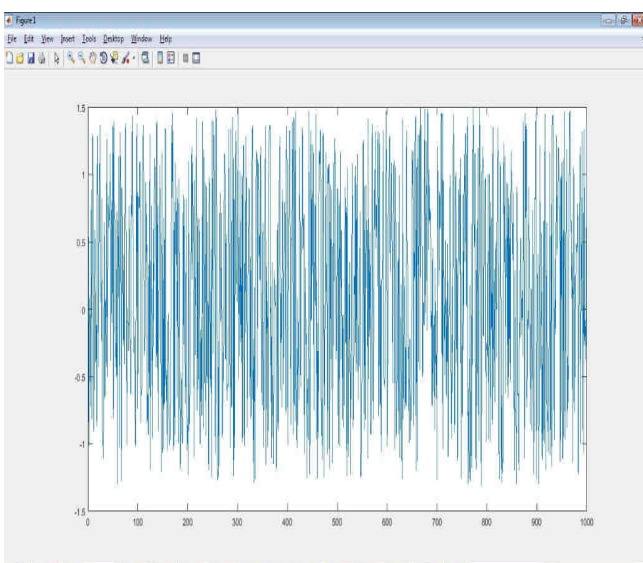


Figure 5: Raw ECG data of Patient 3

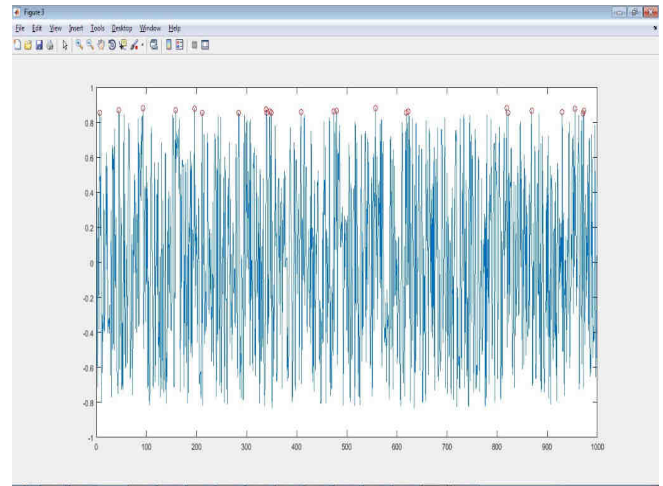


Figure 6: Raw ECG data of Patient 4

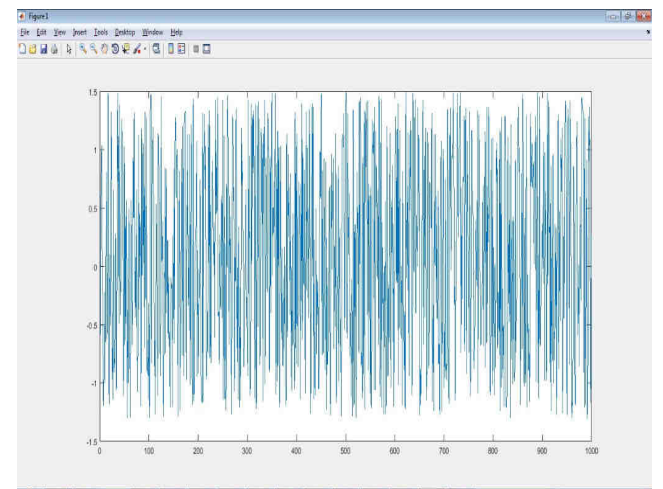


Figure 7: Raw ECG data of Patient 5

(2) Signal Preprocessing

In this stage, low frequency signal can be removed using filters. Different types of noises like frequency interference, base drift etc. are removed. In the first place, the original signal is filtered and amplified at higher frequency level. Then, we obtain a noise free signal to work upon.

Filtered Real ECG Signals:

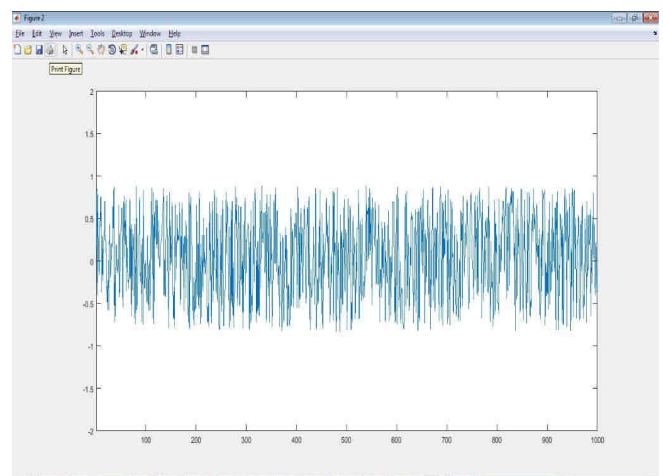


Figure 8: Filtered ECG signal of Patient 1

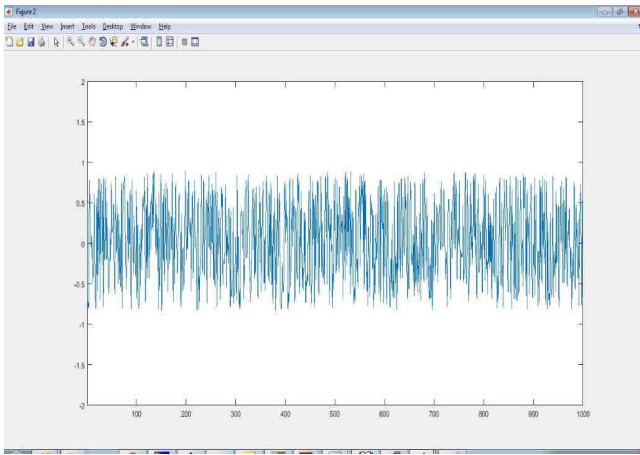


Figure 9: Filtered ECG signal of Patient 2

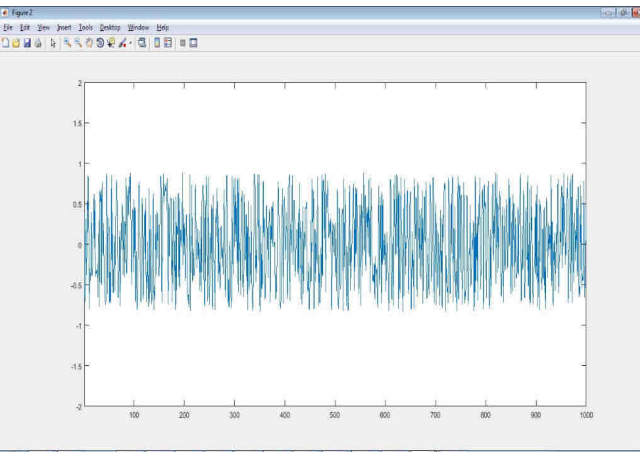


Figure 10: Filtered ECG signal of Patient 3

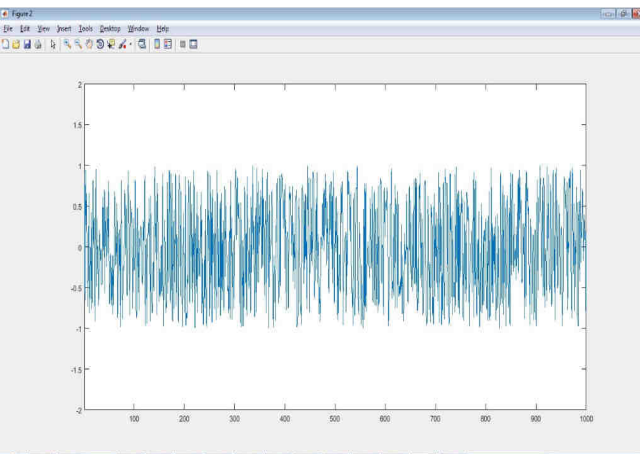


Figure 11: Filtered ECG signal of Patient 4

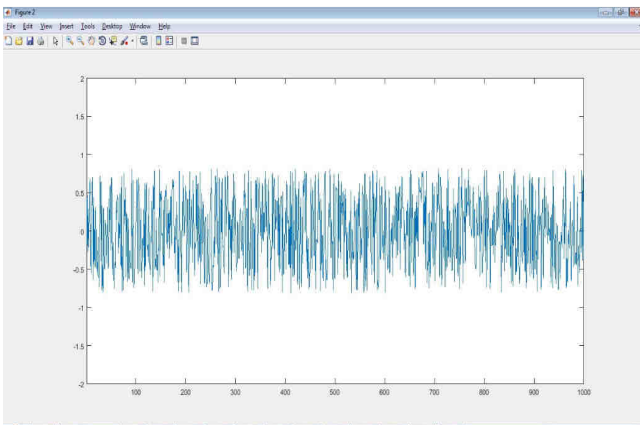


Figure 12: Filtered ECG signal of Patient 5

(3) Detection of Clinically Important Parameters

Fast Walsh-Hadamard Transform is used to determine the QRS complex and various other parameters used for comparison with normal ECG signal.

The FWHT is a suboptimal, non-sinusoidal, orthogonal transformation that decomposes a signal into a set of orthogonal, rectangular waveforms called Walsh functions. The transformation has no multipliers and is real because the amplitude of Walsh (or Hadamard) functions has only two values, +1 or -1. Therefore, FWHTs are used in many different applications including processing of medical signals.

Graphical determination of peaks as obtained:

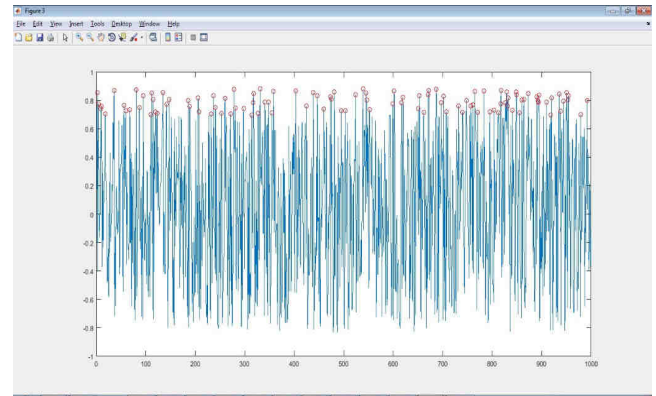


Figure 13: Peaks obtained on filtered ECG signal for Patient 1

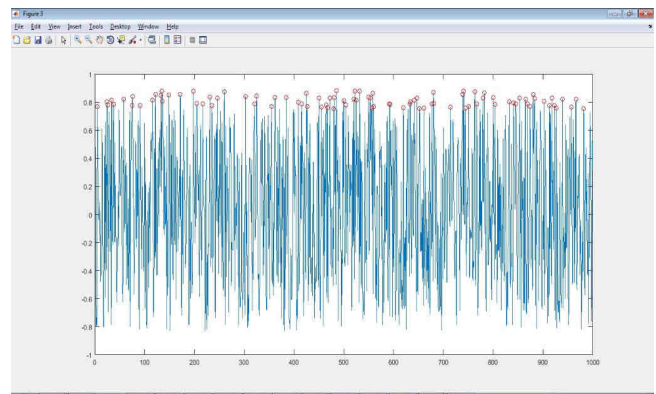


Figure 14: Peaks obtained on filtered ECG signal for Patient 2

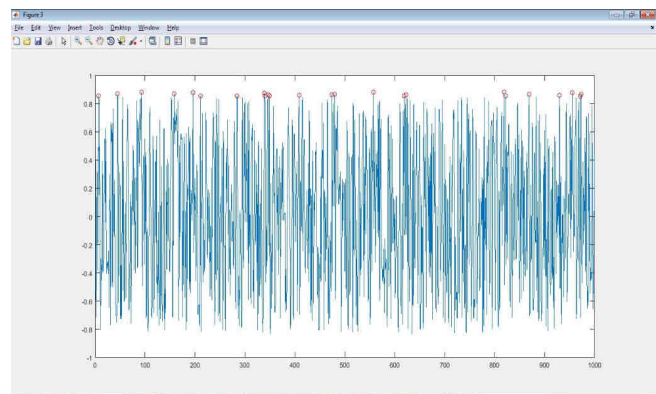


Figure 15: Peaks obtained on filtered ECG signal for Patient 3

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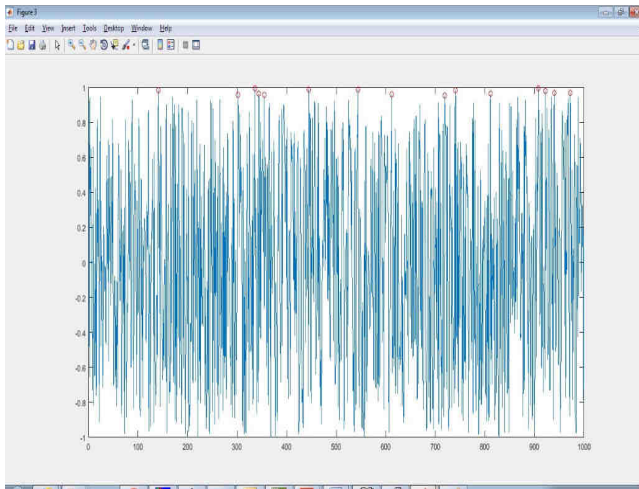


Figure 16: Peaks obtained on filtered ECG signal for Patient 4

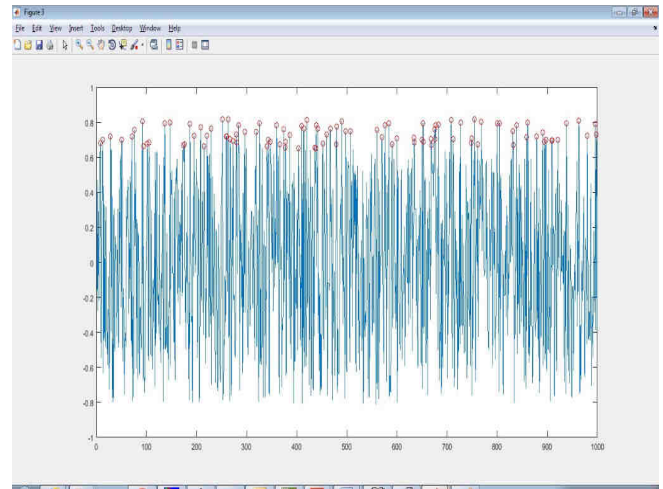


Figure 17: Peaks obtained on filtered ECG signal for Patient 5

(4) Statistical Analysis

After obtaining the various clinically important parameters from the ECG using the FWHT, these parameters are compared with the normal ECG parameters using MATLAB for gaining an insight into the Cardiac Hypertrophy.

Analysis:

	NORMAL PERSON ECG DATA	CARDIAC HYPERTROPHY PATIENTS' ECG DATA				
		PATIENT1	PATIENT2	PATIENT3	PATIENT4	PATIENT5
P WAVE AMPLITUDE (mV)	2.50	2.61	2.72	2.465	3.20	3.09
P WAVE DURATION(Sec)	0.12	0.092	0.1	0.10	0.078	0.135
QRS COMPLEX AMPLITUDE (mV)	3.00	2.73	2.41	3.07	3.21	2.81
QRS COMPLEX DURATION(Sec)	0.12	0.097	0.151	0.21	0.146	0.113
T WAVE AMPLITUDE (mV)	0.20	0.27	0.31	0.25	0.23	0.29
T WAVE DURATION(Sec)	0.16	0.16	0.21	0.17	0.14	0.16
R-R DURATION(Sec)	0.6-1.2	1.27	1.2	1.30	1.25	1.22
P-R INTERVAL(Sec)	0.12-0.2	0.15	0.17	0.17	0.15	0.15
P-R DURATION(Sec)	0.05-0.12	0.11	0.17	0.07	0.09	0.10
S-T INTERVAL(Sec)	0.32	0.32	0.35	0.28	0.29	0.28
S-T ELEVATION (mV)	0.20	0.24	0.27	0.23	0.25	0.25
S-T DURATION(Sec)	0.08-0.12	0.11	0.13	0.10	0.11	0.11
Q-T INTERVAL(Sec)	0.42	0.47	0.51	0.39	0.45	0.39

Hypertrophy can be diagnosed on a high specificity ECG. In left Ventricular Hypertrophy, since, the myocardium of the left ventricle thickens, the electrical activation passes through a larger mass of myocardium, thus, ventricular depolarization i.e. amplitude of QRS complex increases. Also, if there is an abnormal thickening of the myocardium, then the electrical activity takes a long time to traverse the heart, thereby widening the QRS complex. For, left ventricular hypertrophy, QRS duration ≥ 90 ms is a criterion. In Right Ventricular Hypertrophy, the cause is either a lung disease or a congenital heart disease. QRS duration < 120 ms is a criterion.

This can help physicians to find the real cause of QRS change and provide a reference for diagnosis some diseases. The proposed method of evaluating the clinically important parameters using MATLAB as a powerful tool is very effective in determining the values accurately. The measurement of QRS amplitude and duration done with the

help of Fast Walsh Hadamard Transform, as shown in the table above, give accurate values and thus can help physicians to find the real cause of QRS change and provide a reference for diagnosing diseases. The combination of QRS amplitude and duration vary and does not lie within the permissible limits, thereby determining Cardiac Hypertrophy.

VI. CONCLUSION

MATLAB has immense effect on ECG signal processing. It is very powerful, useful and easy to use tool. MATLAB if used judiciously can help a person to monitor the heart health easily. The most crucial step in the analysis of ECG is to carefully detect the signal waves of P, QRS,

T. MATLAB makes use of simple mathematics functions which accurately help in detecting the various peaks and other nonstandard shapes in the ECG signal. Digital Signal Processing is employed as Mathematical signal processing in MATLAB, which helps in the statistical analysis of the results obtained.

This paper proposed a powerful and accurate MATLAB algorithm to calculate all the clinically important parameters required for the systematic study of the analysis of the ECG signal to determine Cardiac Hypertrophy. We applied the algorithm to the ECG signals obtained from MIT Database. The results obtained through the proposed algorithm are indicative of the high classification correct rate and also an effective measurement of all the clinically important parameters. The algorithm can be used to automatically generate the various required parameters and thus can be of immense help to the physicians for early diagnosis of Cardiac Hypertrophy.

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