WAVELET BASED VENTRICULAR TACHYARRHYTHMIA (VT) DETECTION SYSTEM

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ABSTRACT

WAVELET BASED VENTRICULAR
TACHYARRHYTHMIA (VT) DETECTION
SYSTEM

The most dangerous of heart diseases ventricular tachyarrhythmia (VT) is very difficult to detect. Our project, an amalgamation of research and application development uses a novel wavelet based algorithm for detecting VT. This project is done in collaboration with Armed Forces Institute of Cardiology, National Institute of Heart Diseases (AFIC-NIHD)

Wavelet transform has emerged over recent years as a powerful time–frequency analysis tool favored for the interrogation of complex non-stationary signals. The proposed algorithm uses an efficient method for detecting VT in wavelet pre-processed ECG signals. A MATLAB routine using built in library functions for pre-processing removes high frequency noise. The preprocessed signal is applied to the Spectral Algorithm (SPEC) which works in frequency domain and analyses the energy content. If the algorithm decides that the ECG part contains VT, the result is accepted as true and no further investigation is required. Otherwise a further investigation is carried out to confirm the result or disprove it. The terminal parts of the ECG signal are processed with a continuous wavelet transform, which leads to a time-frequency representation of the signal. The diagnostic feature vectors are obtained by subdividing the representations into several regions and by processing the sum of the decomposition coefficients belonging to each region. Wavelet based efficient algorithms are used for detection of VT. With these methods, underlying features within the VT waveform are made visible in the wavelet time-scale half space. The proposed algorithms overcome the non-sensitivity of SPEC

algorithm utilizing its highly specific nature to the fullest. An exhaustive testing exemplified higher sensitivity, predictivity and specificity, enabling the cardiologists and electro physiologists to detect VT with accuracy of more than 85%.

DECLARATION

No portion of the work presented in this dissertation has been submitted in support of any other award or qualification either at this institution or elsewhere.

DEDICATION

In the name of Allah, the Most Merciful, the Most Beneficent

To our parents, without whose unflinching support and unstinting cooperation, a work of this magnitude would not have been possible

ACKNOWLEDGMENTS

We are eternally grateful to Almighty Allah for bestowing us with the strength and resolve to undertake and complete the project.

We gratefully recognize the continuous supervision and motivation provided to us by our Project Supervisor, Chief Instructor (MCS-NUST), Brig Dr. MUHAMMAD AKBAR. No words how rich would do justice to the contribution of Brig Dr. IMRAN MAJEED (Head of Department Clinical Cardiac Electrophysiology AFIC-NIHD). Not only is he a cardiologist of international repute but also the fore runner in R and D at AFIC. Being the only electro physiologist in Pakistan, he has an obvious desire to see people exploring this field. Our gratitude goes to Prof. Dr. ANTON AMANN from Univ.-Clinic for Anesthesia, Austria for his guidance in algorithms related problems, Mr. RAHAT ABBAS (PIEAS) for his help regarding wavelet decomposition and its application. Special thanks to Dr. Hamid Ali Shah (General Physician Santorini, Greece) for teaching us ECG basics .We are grateful to the staff of cardiac electrophysiology department for being very tolerant and helpful with our work. We deeply treasure the unparallel support and tolerance that we received from our friends for their useful suggestions that helped us in completion of this project. We are also deeply obliged to our families for their never ending patience and support for our mental peace and to our parents for the strength that they gave us through their prayers.

A word of thanks to the MILITARY COLLEGE OF SIGNALS (MCS) as it had been our foundation and has made us capable to undertake the project.

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Chapter 1

1 Introduction

1.1 Preface

Over the past decade, significant advances were made in the research, diagnosis, and treatment of cardiovascular diseases. Such progress was in every sphere of cardiology that includes non-invasive, minimally invasive, and invasive technologies. Interpretive electrocardiography, cardiac pacemakers, cardiac stents, and angioplasty are some areas where the progress has been significant. Non-invasive methods of diagnosis of cardiac disorders involve digital recording of cardiac signals at the body surface (chest) and subsequent computerized analysis. Such methods and instruments provide a vital first step to the diagnosis of the heart without involving surgical procedures. One such non-invasive field is High Resolution Electrocardiography (HRECG). A high-resolution electrocardiogram detects very low amplitude signals in the ventricles called 'Late Potentials' (VLP) in patients with abnormal heart conditions. A standard electrocardiogram cannot detect these signals. The presence of late potentials is widely accepted to have prognostic significance in patients after Acute Myocardial Infarction (AMI). The presence of VLPs is indicative of increased risk for subsequent occurrence of arrhythmic events, mainly sustained ventricular tachycardia.

Electrocardiography signal is electric measure of heart activity. Atrial and ventricular of heart contract and expand to pump the blood from lungs to body and vise versa. An arrhythmia is a change in the regular rhythm of heartbeat. All the arrhythmias are not dangerous. The ventricular arrhythmias are considered more dangerous than atrial arrhythmias. The ventricular tachyarrhythmias have heart rate higher than normal. Ventricular Tachyarrhythmia (VT) is responsible for 75% to 85% of sudden deaths in persons with heart problems.

1.2 Human Heart Synopsis

The heart weighs between 7 and 15 ounces (200 to 425 grams) and is a little larger than the size of the fist. By the end of a long life, a person's heart may have beaten (expanded and contracted) more than 3.5 billion times. In fact, each day, the average heart beats 100,000 times, pumping about 2,000 gallons (7,571 liters) of blood.

The heart is located between lungs in the middle of the chest, behind and slightly to the left of breastbone (sternum). A double-layered membrane called the pericardium surrounds heart like a sac. The outer layer of the pericardium surrounds the roots of heart's major blood vessels and is attached by ligaments to spinal column, diaphragm, and other parts of human body. The inner layer of the pericardium is attached to the heart muscle. A coating of fluid separates the two layers of membrane, letting the heart move as it beats, yet still be attached to the body.

Human heart has 4 chambers. The upper chambers are called the left and right atria, and the lower chambers are called the left and right ventricles. A wall of muscle called the septum separates the left and right atria and the left and right ventricles. The left ventricle is the largest and strongest chamber in your heart. The left ventricle's chamber walls are only about a half-inch thick, but they have enough force to push blood through the aortic valve and into the body.

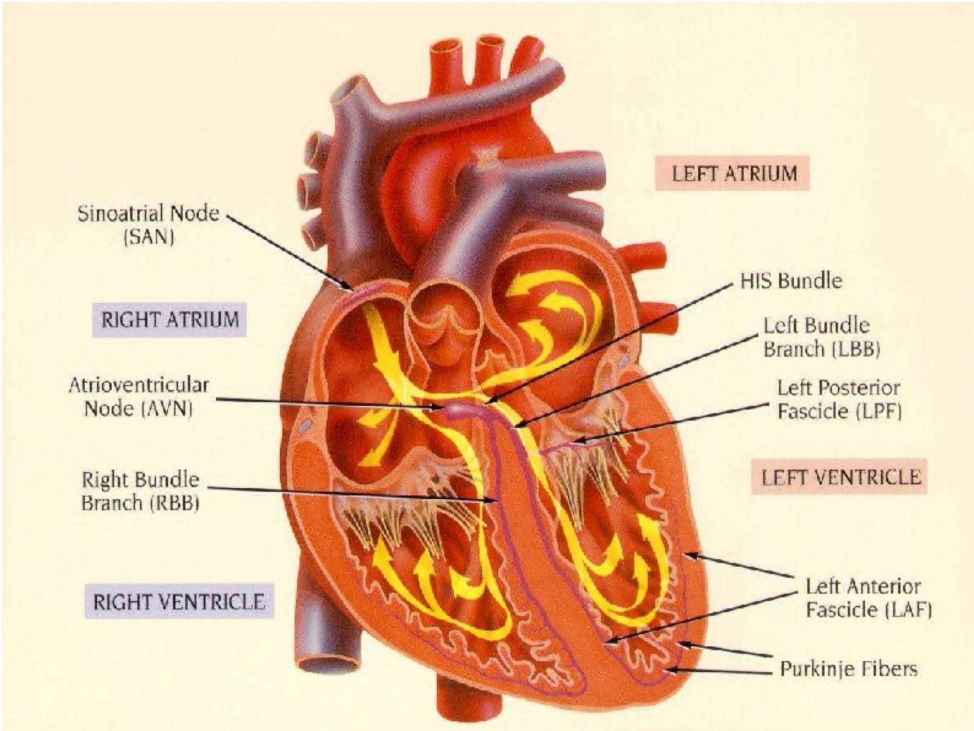


Figure 1-1: Human Heart

1.2.1 The Heart Valves

Four types of valves regulate blood flow through the human heart:

- The tricuspid valve regulates blood flow between the right atrium and right ventricle.
- The pulmonary valve controls blood flow from the right ventricle into the pulmonary arteries, which carry blood to lungs to pick up oxygen.
- The mitral valve lets oxygen-rich blood from the human lungs pass from the left atrium into the left ventricle.

The aortic valve opens the way for oxygen-rich blood to pass from the left ventricle into the aorta, body's largest artery, where it is delivered to the rest of the body. The conduction system is composed of specialized muscle tissue that generates and distributes the action potentials that stimulate the cardiac muscle fibers to contract. These tissues are found in the sinoatrial (SA) node, atrioventricular (AV) node, atrioventricular

(AV) bundle (bundle of His), bundle branches, and conduction myofibres (Purkinje fibres). All cardiac muscle is capable of self-excitation; that is, it spontaneously and rhythmically generates action potentials that result in contraction of the muscle. The normal resting rate of self-excitation of the sinoatrial node is about 75 times per minute in adults. Since this rate occurs faster than that of other cardiac muscle fibres, the SA node is called the "pacemaker".

1.3 ECG and Ventricular Tachyarrhythmia (VT)

1.3.1 Electrocardiogram (EKG,ECG):

As the heart undergoes depolarization and repolarization, the electrical currents that are generated spread not only within the heart, but also throughout the body. This electrical activity generated by the heart can be measured by an array of electrodes placed on the body surface. The recorded tracing is called an electrocardiogram (ECG, or EKG). The different waves that comprise the ECG represent the sequence of depolarization and repolarization of the atria and ventricles. The ECG is recorded at a speed of 25 mm/sec, and the voltages are calibrated so that 1 mV = 10 mm in the vertical direction. Therefore, each small 1-mm square represents 0.04 sec (40 msec) in time and 0.1 mV in voltage.

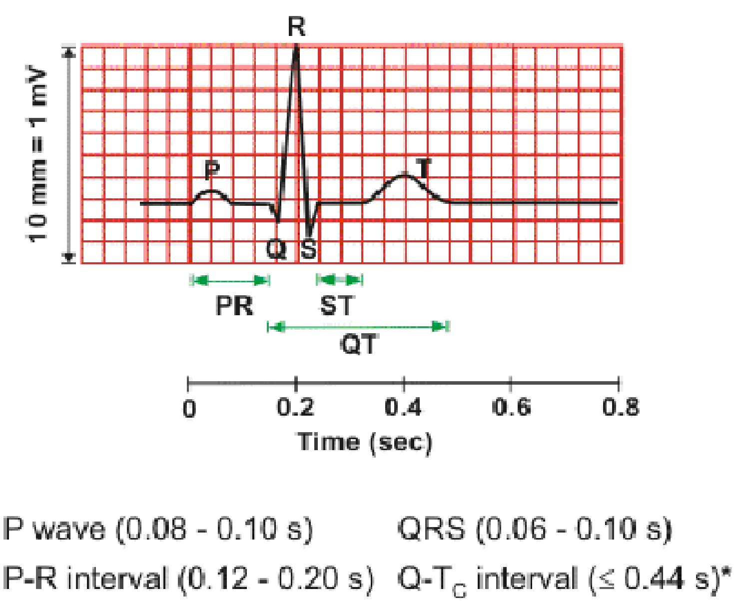


Figure 1-2: ECG Signal Characteristics

The **P wave** represents the wave of depolarization that spreads from the SA node throughout the atria, and is usually 0.08 to 0.1 seconds (80-100 ms) in duration. The brief isoelectric (zero voltage) period after the P wave represents the time in which the impulse is traveling within the AV node (where the conduction velocity is greatly retarded) and the bundle of His.

The period of time from the onset of the P wave to the beginning of the QRS complex is termed the **P-R interval**, which normally ranges from 0.12 to 0.20 seconds in duration. This interval represents the time between the onset of atrial depolarization and the onset of ventricular depolarization. If the P-R interval is >0.2 sec, there is an AV conduction block, which is also termed a first-degree heart block if the impulse is still able to be conducted into the ventricles.

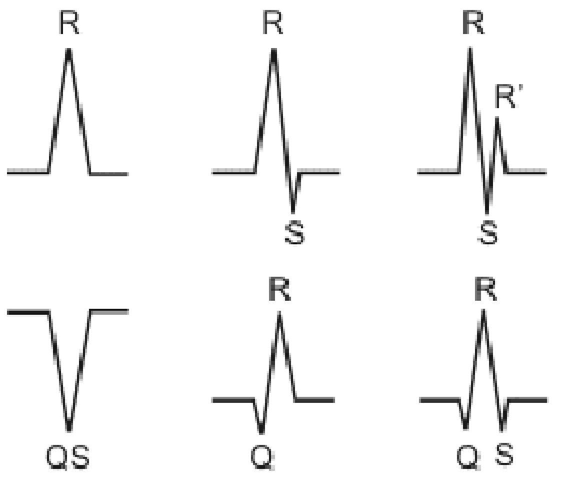


Figure 1-3: Different QRS Complexes

The **QRS complex** represents ventricular depolarization. The duration of the QRS complex is normally 0.06 to 0.1 seconds. This relatively short duration indicates that ventricular depolarization normally occurs very rapidly. If the QRS complex is prolonged (> 0.1 sec), conduction is impaired within the ventricles. This can occur with bundle branch blocks or whenever a ventricular foci (abnormal pacemaker site) becomes the pacemaker driving the ventricle.

Such an ectopic foci nearly always results in impulses being conducted over slower pathways within the heart, thereby increasing the time for depolarization and the duration of the QRS complex.

The shape of the QRS complex in the above figure is idealized. In fact, the shape changes depending on which recording electrodes are being used. The shape will also change when there is abnormal conduction of electrical impulses within the ventricles. The figure to the right summarizes the nomenclature used to define the different components of the QRS complex.

The isoelectric period (**ST segment**) following the QRS is the time at which the entire ventricle is depolarized and roughly corresponds to the plateau phase of the ventricular action potential. The ST segment is important in the diagnosis of ventricular ischemia or hypoxia because under those conditions, the ST segment can become either depressed or elevated.

The **T wave** represents ventricular repolarization and is longer in duration than depolarization (i.e., conduction of the repolarization wave is slower than the wave of depolarization). Sometimes a small positive U wave may be seen following the T wave (not shown in figure at top of page). This wave represents the last remnants of ventricular repolarization. Inverted or prominent U waves indicates underlying pathology or conditions affecting repolarization.

The **Q-T interval** represents the time for both ventricular depolarization and repolarization to occur, and therefore roughly estimates the duration of an average ventricular action potential. This interval can range from 0.2 to 0.4 seconds depending upon heart rate. At high heart rates, ventricular action potentials shorten in duration, which decreases the Q-T interval. Because prolonged Q-T intervals can be diagnostic for susceptibility to certain types of tachyarrhythmias, it is important to determine if a given Q-T interval is excessively long. In practice, the Q-T interval is expressed as a "corrected Q-T (QTc)" by taking the Q-T interval and dividing it by the square root of the R-R interval (interval between ventricular depolarizations). This allows an assessment of the Q-T interval that is independent of heart rate. Normal corrected Q-Tc intervals are less than 0.44 seconds.

There is no distinctly visible wave representing atrial repolarization in the ECG because it occurs during ventricular depolarization. Because the wave of atrial repolarization is relatively small in amplitude (i.e., has low voltage), it is masked by the much larger ventricular-generated QRS complex.

ECG tracings recorded simultaneous from different electrodes placed on the body produce different characteristic waveforms.

1.3.2 Ventricular Tachyarrhythmia (VT):

Ventricular Tachyarrhythmias are fast heart beat arrhythmias produced in lower part of heart called Ventricular. There are three main categories of ventricular tachyarrhythmias i.e. Ventricular Tachycardia (VT), Ventricular Flutter (VFl) and Ventricular Fibrillation (VF). Ventricular fibrillation (VF) is a severely abnormal heart rhythm (arrhythmia) that, unless treated immediately, causes death.

- **Ventricular Flutter**

Ventricular Flutters (VFl) are high frequency (250- 350/min) beats. The ECG signal looks like sinusoidal as shown in Figure 1. Due to high rate of contraction of heart chambers the time of blood flow into the chamber becomes very small, so very little blood flows to body. The person who is experiencing VFl is close to unconsciousness.

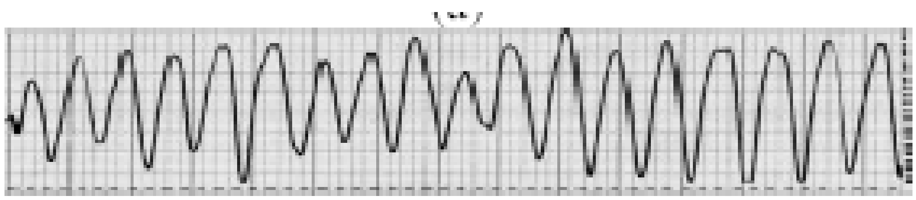


Figure 1-4: Ventricular Flutter

- **Ventricular fibrillation**

Ventricular fibrillation ("v-fib", often abbreviated VF) describes the electrical activity associated with the quivering of the ventricles. When Don Corleone is shot, quivering Fredo is unable to successfully wield a gun. Quivering ventricles are about as effective as quivering Fredo- they cannot pump blood. While functional atria are a prerequisite for playing tennis or jogging, functional ventricles are a prerequisite for staying alive. Thus, untreated v-fib can progress to death within minutes. You can understand why v-fib is one of the evil rhythms. When someone suddenly drops dead from a cardiac arrest, v-fib is likely to blame.

The pattern for ventricular fibrillation is... well, there really is no pattern. It is random electrical activity. Sometimes the amplitude of the waves is large (coarse VF), while other times the amplitude is so small (*fine VF*) that the rhythm is almost *asystole*. It has almost a "kindergarten artwork" quality to it.

As the minutes pass, cells in the body become damaged due to the lack of oxygenated blood. Among these are cells of the heart. As the heart dies, it loses its ability to conduct electricity. Coarse v-fib will turn into fine v-fib, and fine v-fib will transition into asystole.

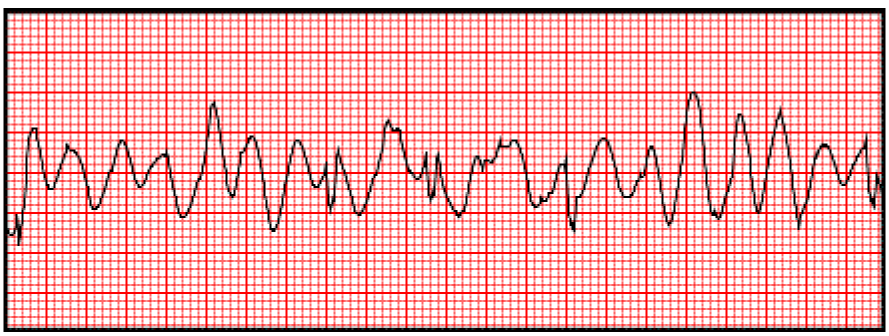


Figure 1-5: Ventricular fibrillation (coarse)

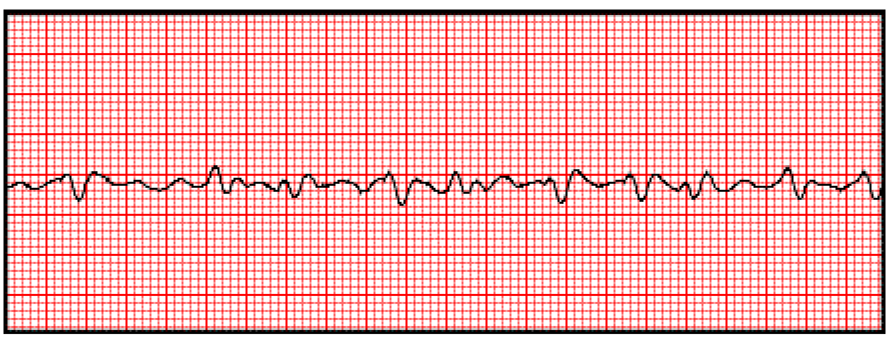


Figure 1-6: Ventricular fibrillation (fine)

- **Ventricular tachycardia**

Ventricular tachycardia (V-tach, often abbreviated VT) refers to a rhythm that arises from the ventricles causing the heart to beat at a rate faster than 100 beats per minute. The ventricular rate is usually above 120 beats/min and may exceed 250 beats/min. At some point, the ventricles may beat so frequently that there is not adequate time for the blood to refill. A patient in ventricular tachycardia MAY or MAY NOT have a pulse.

A heart in VT is vulnerable to going into ventricular fibrillation. In fact, the common sequence of arrhythmias in patients who die in this rhythm is: V-tach to V-fib to asystole.

The QRS complex will be wider than 0.12 seconds. Figure 9-5 shows the stereotypical V-tach, but not all cases look like this.

Unless you have been trained to distinguish a ventricular QRS complex from a wide QRS of non-ventricular origin, then you should call a tachycardia with wide QRS complexes a "wide complex tachycardia."

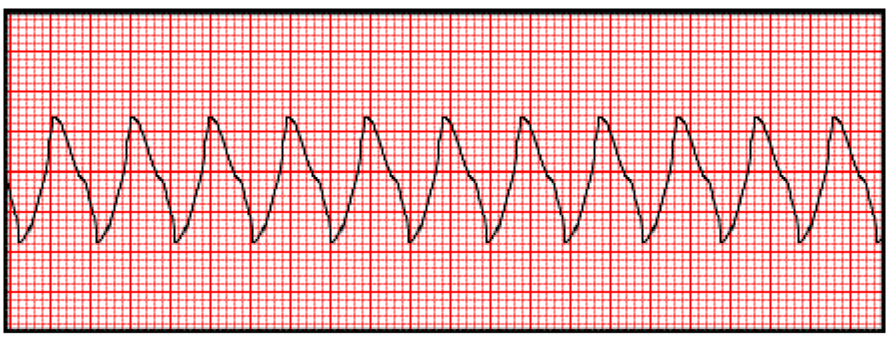


Figure 1-7: Ventricular tachycardia

Other Ventricular Related Problems:

- **Ventricular escape**

Ventricular escape, often called *idioventricular escape*, is when an ectopic "backup" pacemaker in the ventricles kicks in. A few things can cause this :

1. The sinus and junctional pacemakers have failed
2. There is a block that prevents impulses of the sinus (or junctional) pacemaker from reaching the ventricles.

Although it is considered a "backup" rhythm, it is only slightly more compatible with life than asystole. The intrinsic rate of a ventricular pacemaker is 20 - 40 times/minute. In other words, this is a very bad rhythm.

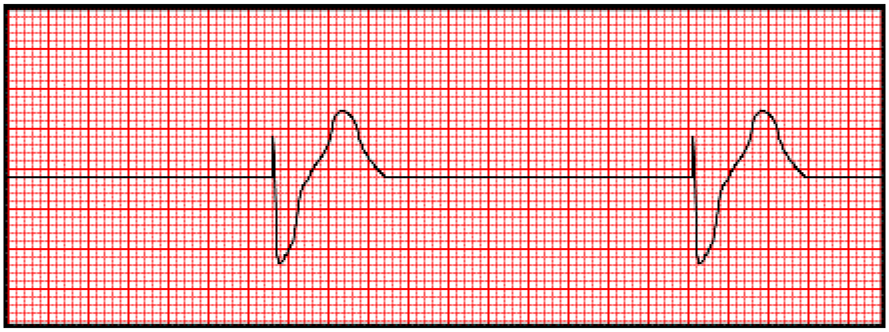


Figure 1-8: Idioventricular rhythm

1.4 The Problem:

Due to high risk of sudden deaths by ventricular tachyarrhythmias, there is a need of an efficient, accurate and sensitive system in order to help the Cardiologists and Electro Physiologists for detection of ventricular tachyarrhythmia (VT).

1.4.1 Challenges:

- Study of Related Human Anatomy and Electro Physiology. The electrical signals being produced at the human heart is a complex phenomenon itself falling under the medical Super Specialty of "Electro Physiology", a complex and rich field of study by itself.

- Non-Familiarization with Medical Terms. Being engineering students, we all were totally alien to the medical terminologies and theories, the understanding of which was paramount for the accomplishment of the project. Particularly the complex cardiac phenomena and its subsequent implications with regards to the changing potentials were needed to be explored in minutest details. This issue could not be condoned and warranted immediate reprisal and the same was sought through extensive meetings with Brig Dr. Imran Majeed and congruent study of Cardiac manuals.

- Previously Unfathomed Bio-Engineering Domain. Our project is basically research oriented and pertains to a domain that has never been practically explored before. Therefore sufficient reference material was not available especially from conventional sources. The problem was addressed with individual contacts and specialized references. The problem was augmented by the fact that DSP had never been a subject on our academic agenda, and we had to start from zilch.

1.5 Concept Evolution

The project has been evolved in a series of steps as the search started early in the fifth semester about a year and a half back. There were many triggering events and motivating factors that led us to select this project of great caliber. In search of such a project we went to various organizations like PTCL, CARE, Pakistan Railway and NIIT but eventually we landed up in AFIC/NIHD. We were convinced that we should do our degree project in the field of biomedical engineering. Thus we were enthused to take up this uphill task. The options available were to enhance the functionalities of a Cardiac Monitor and ECG machine but due to the lack of involvement of hardware and the ethics of technology the options were dropped since they the machines were patented .After rigorous meetings and interactions with DS and domain expert it as then decided to develop an altogether new system which takes the ECG signal as input and provide VT Detection. Each day lead us to new venues of exploration and learning and gradually the system idea became clear.

1.6 The Project

1.6.1 SCOPE

The project has a stupendous scope for the time to come .This is one of the first project of its kind in Pakistan in the field of biomedical engineering to perform Beat to Beat

Analysis for VT Detection. The project involves both the hardware and software integrated/interfaced together via a parallel port.

The project scope includes its colossal market value and great research potential. The product cannot only be installed in hospitals but it also invites new courses of undergraduate and even graduate level for research and development. The system places a new concept in the field of non-invasive treatments in general and the field of cardiology in particular.

1.6.2 Objectives

The project had many multi dimensional objectives which were achieved with the course of time by ALLAH‘s Grace. These objectives are delineated as follows:

1.6.2.1 Immediate Objective

- To develop a complete detection system capable of acquiring ECG data from available systems at AFIC.
- To provide a generalized solution to the problem by taking under consideration the specific system requirements of AFIC.
- To effectively apply the Wavelet Transform to solve our problem in the best possible way.
- To develop a GUI based software on computer showing the ECG analysis of the input signal.
- To built user friendly architecture for VT detection of both the static and dynamic data.
- To apply all the engineering skills, hardware knowledge and software expertise in the development of this system.

1.6.2.2 Future / Subsequent Objectives

The future objectives of developing the system are as follows;

- After validation and thorough experimentation this system can be installed at the hospitals.

- The software can be used to detect all types of VT with greater efficiency and accuracy.

1.6.2.3 Project Beneficiaries

The project beneficiaries include the hospital for which the system has been developed i.e. AFIC/NIHD. Apart from that this project can benefit not only those who want to take up the field of bio-medical research engineering but also the ones who are interested in Detection Systems Development. Involving many dimension of exploration this project is capable of producing new vistas of R & D in the college.

1.6.2.4 Project Title

Business Title: VT DetS

Technical Title: A Wavelet Ventricular Tachyarrhythmia Detection System

Project Logo:

Figure 1-9: VT Detection System Logo

1.6.2.5 Project Descriptions

The system contains the following vital features which are to be known by the user;

Platform. The system will be implemented on Windows XP (due to familiarity of end user) machine. It is recommended that the service be run on minimum Intel based 1.0 GHz microprocessor with minimum of 256 MB RAM since the system is real time.

Development Environment:

Software. The software main module which is in turn divided into many sub modules is made in MATLAB Version 7.0. In addition help and guidance was taken from MATLAB toolboxes and also from the internet. C++ programs and Libraries are also used by the software. The methodology followed is Spiral Model

Testing Environment. Testing was conducted after the successful completion of each module and in case of an error a bug report was being generated. The resting was conducted in accordance with IEEE standard 1058a-1998.

1.6.2.6 Project Specifications

The Project cardiac Imaging is being developed for AFIC /NIHD Electrophysiology Department; it is aimed at detecting VT with higher accuracy, sensitivity, specificity and Predictivity. Thus laying a new concept in the field of Non-Invasive treatment and elctro cardiography research. This system also shows different views of ECG storing the valuable information. These are the functionalities which are not provided in conventional ECG system.

Project Limitations / Constraints

The software was tested and analyze thoroughly and the limits and constraints of the system are as follows:

- The system is compatible with Windows environment but does not work to the perfection on Linux or Macintosh Environment. This is due to the missing DLL libraries available in Windows.

- The waveform display in CI System is real time but it has to be configured with the deployed ECG System

1.7 Work Breakdown Structure

For the successful completion of the project, the project was divided into main modules and structures. It was ensured that each task being assigned was carried out appropriately and on time.

Requirements Engineering

1. Requirements Elicitation
    i. Interaction with Domain Expert
    ii. Understanding basis of ECG and study related Problems
2. Developing Problem Statement
    i. SRS Preparation
3. Solutions Evaluations
    i. Analyze various options Available (i.e. Platform Compatibility, Language)
    ii. Propose the best Approach to Problem Solution
4. Analysis
    i. Feasibility Study
5. Assignment and Planning
    i. Assignment of Tasks to the syndicate members
    ii. Preparation of Gantt Charts
    iii. Preparation of TimeLine Charts

Literature Review

1. ECG Systems Research Work
2. VT Research Work
3. Wavelet Transform Research Work Study

Software Module

1. Algorithm Design
    i. Parameters Design

ii. Combination of Techniques
iii. Basic Modules
    1. Frequency Components and Duration Detection
    2. Wavelet Analysis
    3. ECG Signal Generator

4. GUI
    i. Real Time ECG Display
    ii. Main Menu
    iii. ECG Analyzer
        1. Step by Step ECG View
        2. All Parameters View
        3. Noise Factor Results
        4. Results and Graphs View

<u>Integration and Testing</u>

- Prepare test Cases
- Black Box Testing
- White Box Testing
- Validation
- Verification

<u>Documentation</u>

Preparation of System Manual
Preparation of Data Dictionary
Detailed Thesis
Research Papers and Publications

User Manuals

Refinement

To refine certain short comings in the System

1.8 Research Objectives

1.8.1 Project Goals and Objectives

The objectives of the project were:

(a) Design and Implement Wavelet based Algorithms

(b) Implement it in MATLAB and C++,

(c) Compare its quality parameters with other standard algorithms available for VT Detection.

1.8.2 Deliverables

Deliverables of the project are:

(a) EXE code of ECG ANALYZER

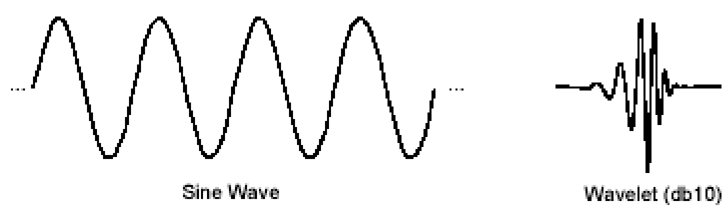
(b) Stored results .dat files for reusability

(c) Comparison Graphs

2 Wavelet Transform

2.1 Definition

By definition *a wavelet is a waveform of effectively limited duration that has an average value of zero.* Wavelet analysis is capable of revealing aspects of data that other signal analysis techniques miss like trends, breakdown points, discontinuities in higher derivatives, and self-similarity. Further, because it affords a different view of data than those presented by traditional techniques, wavelet analysis can often compress or de-noise a signal without appreciable degradation. Indeed, in their brief history within the signal processing field, wavelets have already proven themselves to be an indispensable addition to the analyst's collection of tools and continue to enjoy a burgeoning popularity today. The comparison of wavelets with sine waves, which are the basis of Fourier analysis. Sinusoids do not have limited duration — they extend from minus to plus infinity. And where sinusoids are smooth and predictable, wavelets tend to be irregular and asymmetric.



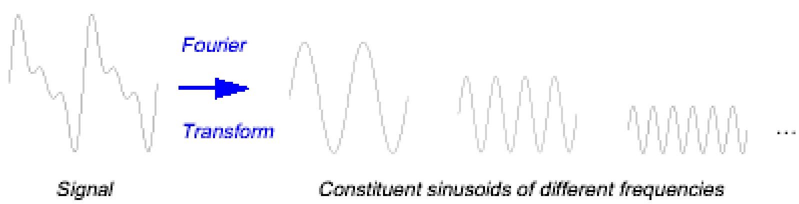
The term wavelet means a small wave. The smallness refers to the condition that this (window) function is of finite length (compactly supported). The wave refers to the condition that this function is oscillatory. The term *mother* implies that the functions with different region of support that are used in the transformation process are derived from one main function, or the mother wavelet. In other words, the mother wavelet is a prototype for generating the other window functions.

Mathematically, the process of Fourier analysis is represented by the Fourier transform:

$$F(\omega) = \int_{-\infty}^{\infty} f(t)e^{-j\omega t}dt,$$

Which is the sum over all time of the signal f(t) multiplied by a complex exponential. (Recall that a complex exponential can be broken down into real and imaginary sinusoidal components.)

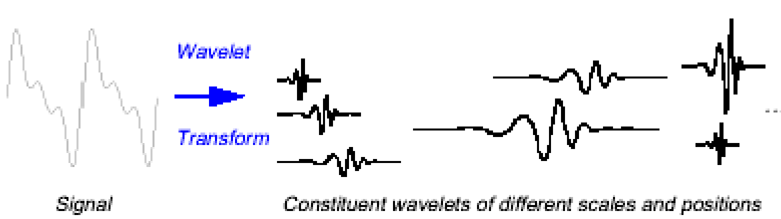
The results of the transform are the Fourier coefficients, which when multiplied by a sinusoid of appropriate frequency, yield the constituent sinusoidal components of the original signal. Graphically, the process looks like:



Similarly, the continuous wavelet transform (CWT) is defined as the sum over all time of the signal multiplied by scaled, shifted versions of the wavelet function:

$$C(scale, position) = \int_{-\infty}^{\infty} f(t)\psi(scale, position, t)dt$$

The results of the CWT are many wavelet coefficients C, which are a function of scale and position. Multiplying each coefficient by the appropriately scaled and shifted wavelet yields the constituent wavelets of the original signal:



2.2 Mathematical Transformations

These are applied to signals to obtain further information from that signal that is not readily available in the raw signal. The frequency spectrum (generated by the Fourier Transform) of a signal shows what frequencies exist in the signal. Intuitively, we all know that the frequency is something to do with the change in rate of something. The information provided by the integral, corresponds to all time instances, since the integration is from minus infinity to plus infinity over time. It follows that no matter where in time the component with frequency "f" appears, it will affect the result of the integration equally as well. In other words, whether the frequency component "f" appears at time t1 or t2, it will have the same effect on the integration. Consider the signal:

$$x(t)=\cos(2*pi*5*t)+\cos(2*pi*10*t)+\cos(2*pi*20*t)+\cos(2*pi*50*t)$$

that is , it has four frequency components of 5, 10, 20, and 50 Hz., all occurring at all times.

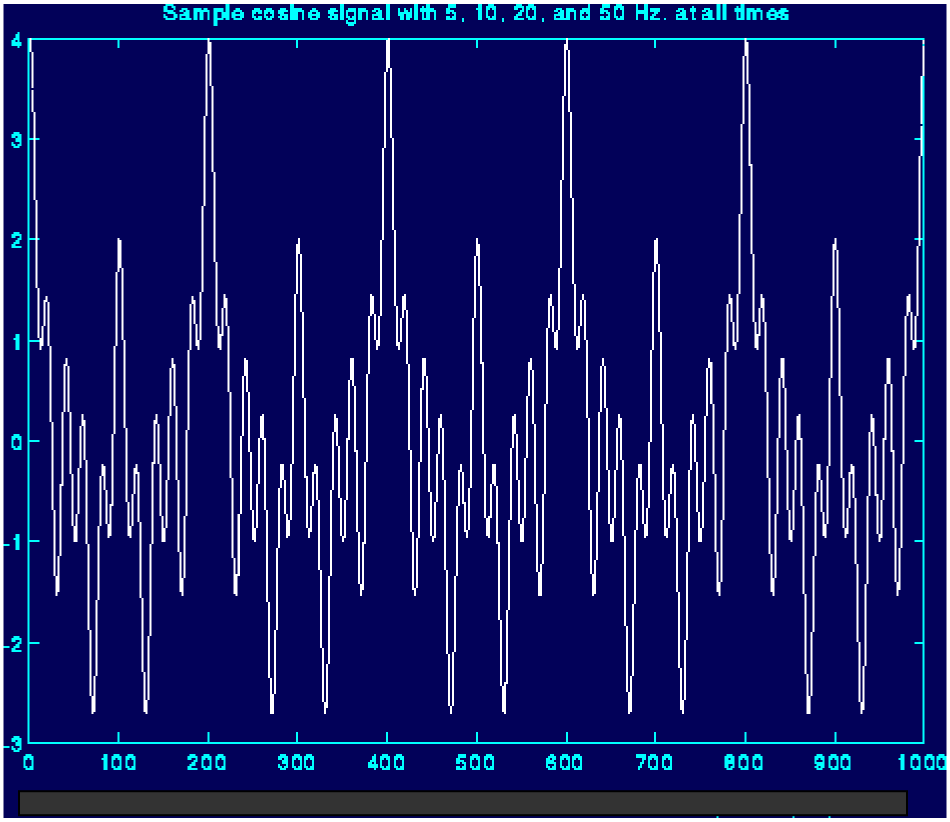


Figure 2-1

And here is the FT of it. The frequency axis has been cut here, but theoretically it extends to infinity (for continuous Fourier transform (CFT). Actually, here we calculate the discrete Fourier transform (DFT), in which case the frequency axis goes up to (at least) twice the sampling frequency of the signal, and the transformed signal is symmetrical.

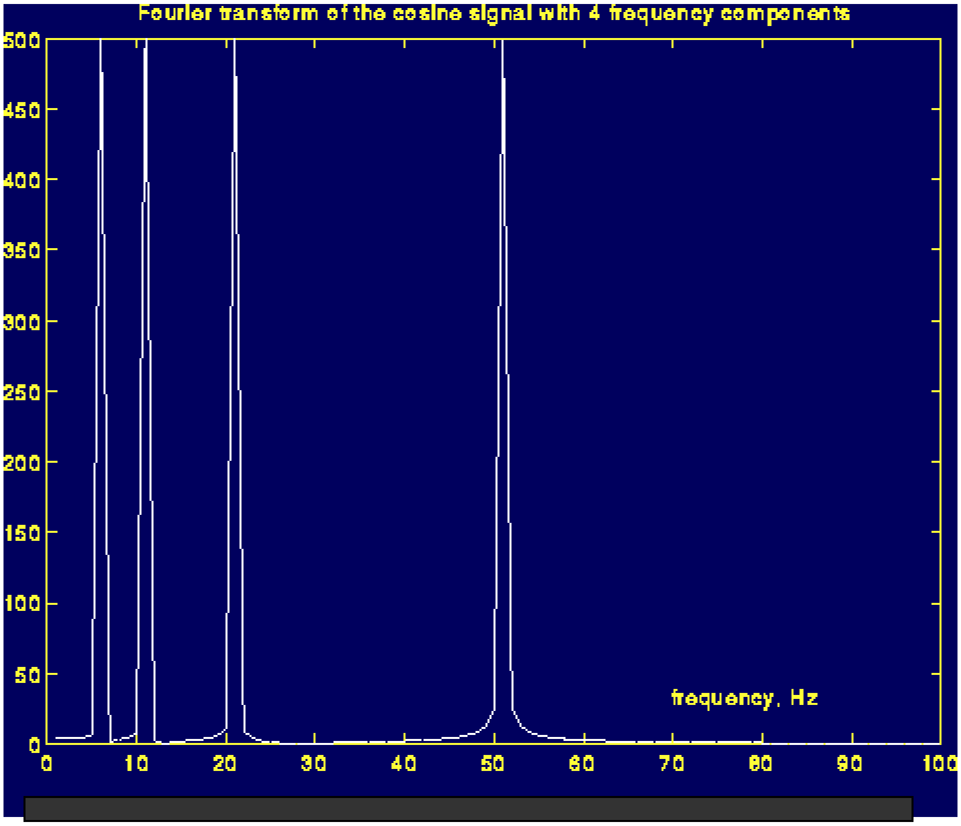


Figure 2-2

Note the four peaks in the above figure, which correspond to four different frequencies. Now, look at the following figure: Here the signal is again the cosine signal, and it has the same four frequencies. However, these components occur at different times.

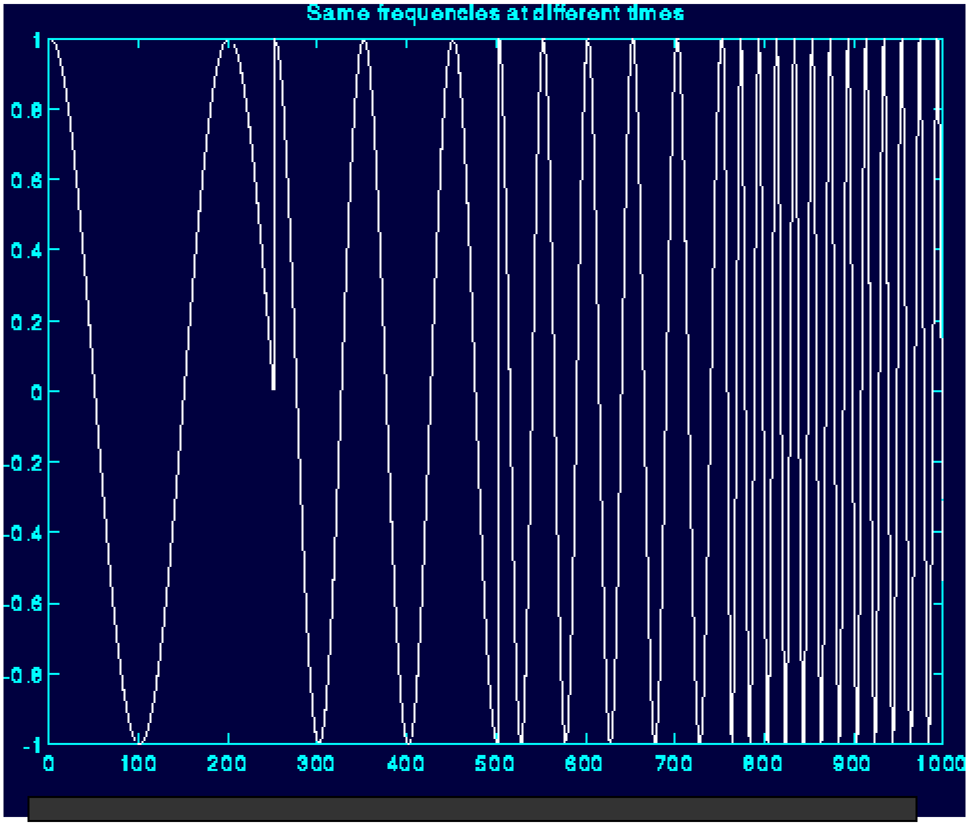


Figure 2-3

And here is the Fourier transform of this signal:

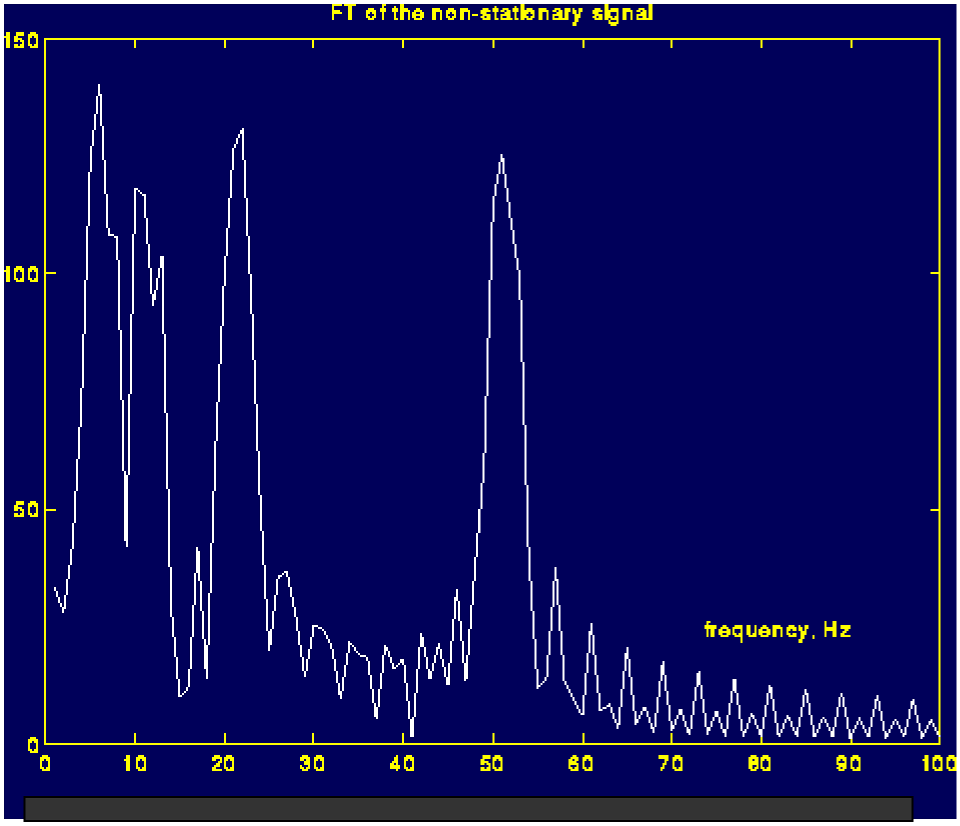


Figure 2-4

look carefully and note the major four peaks corresponding to 5, 10, 20, and 50 Hz. This is why Fourier transform is not suitable if the signal has time varying frequency, FT can be used for non-stationary signals, if we are only interested in what spectral components exist in the signal, but not interested where these occur. However, if this information is needed, i.e., if we want to know, what spectral component occur at what time (interval) , then Fourier transform is not the right transform to use.

2.3 Time Localization in FT and STFT

How are we going to insert this time business into our frequency plots? What was wrong with FT? It did not work for non-stationary signals. If this region where the signal can be assumed to be stationary is too small, then we look at that signal from narrow windows, narrow enough that the portion of the signal seen from these windows are indeed stationary. This approach ended up with a revised version of the Fourier transform, so-called: The Short Time Fourier Transform (STFT).

In STFT, the signal is divided into small enough segments, where these segments (portions) of the signal can be assumed to be stationary. For this purpose, a window function "w" is chosen. The width of this window must be equal to the segment of the signal where its stationarity is valid. This window function is first located to the very beginning of the signal. That is, the window function is located at t=0. Let's suppose that the width of the window is "T" s. At this time instant (t=0), the window function will overlap with the first T/2 seconds. The window function and the signal are then multiplied. By doing this, only the first T/2 seconds of the signal is being chosen, with the appropriate weighting of the window (if the window is a rectangle, with amplitude "1", then the product will be equal to the signal). Then this product is assumed to be just another signal, whose FT is to be taken. In other words, FT of this product is taken, just as taking the FT of any signal.

The result of this transformation is the FT of the first T/2 seconds of the signal. If this portion of the signal is stationary, as it is assumed, then there will be no problem and the obtained result will be a true frequency representation of the first T/2 seconds of the signal. The next step would be shifting this window (for some t1 seconds) to a new location, multiplying with the signal, and taking the FT of the product. This procedure is followed until the end of the signal is reached by shifting the window with "t1" seconds intervals.

The problem with STFT is the fact whose roots go back to what is known as the Heisenberg Uncertainty Principle. This principle originally applied to the momentum and location of moving particles, can be applied to time-frequency information of a signal. Simply, *this principle states that one cannot know the exact time-frequency representation of a signal,* i.e., one cannot know what spectral components exist at what instances of times. What one can know are the time intervals in which certain band of frequencies exist, which is a resolution problem.

The problem with the STFT has something to do with the width of the window function that is used. To be technically correct, this width of the window function is known as the support of the window. If the window function is narrow than it is known as compactly supported. This terminology is more often used in the wavelet world.

As mentioned above, in the FT there is no resolution problem in the frequency domain, i.e., we know exactly what frequencies exist; similarly there is no time resolution problem in the time domain, since we know the value of the signal at every instant of time. Conversely, the time resolution in the FT, and the frequency resolution in the time domain are zero, since we have no information about them. What gives the perfect frequency resolution in the FT is the fact that the window used in the FT is its kernel, the exp {jwt} function, which lasts at all times from minus infinity to plus infinity. Now, in STFT, our window is of finite length, thus it covers only a portion of the signal, which causes the frequency resolution to get poorer. What I mean by getting poorer is that, we no longer know the exact frequency components that exist in the signal, but we only know a band of frequencies that exist.

In FT, the kernel function allows us to obtain perfect frequency resolution because the kernel itself is a window of infinite length. In STFT, window is of finite length, and we no longer have perfect frequency resolution. We may ask why don't we make the length of the window in the STFT infinite, just like as it is in the FT, to get perfect frequency resolution? Well, than we loose all the time information, we basically end up with the FT instead of STFT. To make a long story real short, we are faced with the following dilemma:

If we use a window of infinite length, we get the FT, which gives perfect frequency resolution, but no time information. Furthermore, in order to obtain the stationarity, we have to have a short enough window, in which the signal is stationary. The narrower we make the window, the better the time resolution, and better the assumption of stationarity, but poorer the frequency resolution:

Narrow window ===>good time resolution, poor frequency resolution.

Wide window ===>good frequency resolution, poor time resolution.

2.4 Wavelet – Variable Length Window Function

The Wavelet transform (WT) solves the dilemma of resolution to a certain extent. The wavelet analysis is done in a similar way to the STFT analysis in the sense that the signal is multiplied with a function, similar to the window function in the STFT, and the transform is computed separately for different segments of the time-domain signal. However, there are two main differences between the STFT and the CWT:

- The Fourier transforms of the windowed signals are not taken, and therefore single peak will be seen corresponding to a sinusoid, i.e., negative frequencies are not computed.
- The width of the window is changed as the transform is computed for every single spectral component, which is probably the most significant characteristic of the wavelet transform.

The parameter scale in the wavelet analysis is similar to the scale used in maps. As in the case of maps, high scales correspond to a non-detailed global view (of the signal), and low scales correspond to a detailed view. Similarly, in terms of frequency, low frequencies (high scales) correspond to a global information of a signal (that usually spans the entire signal), whereas high frequencies (low scales) correspond to a detailed information of a hidden pattern in the signal (that usually lasts a relatively short time).

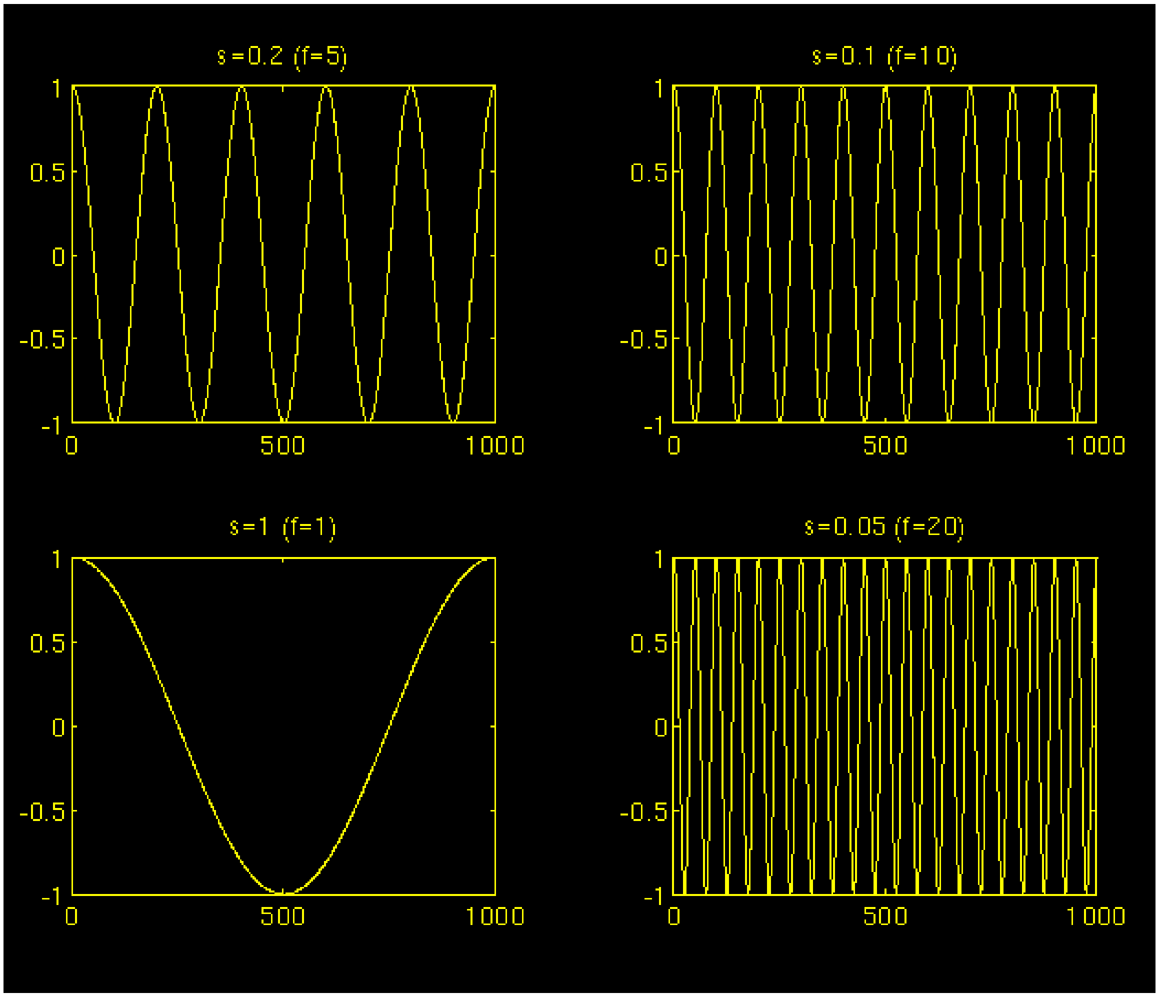
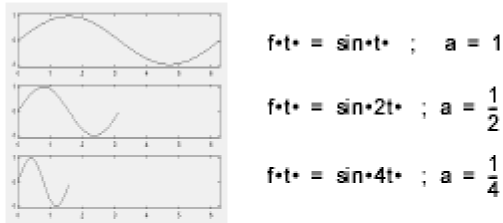
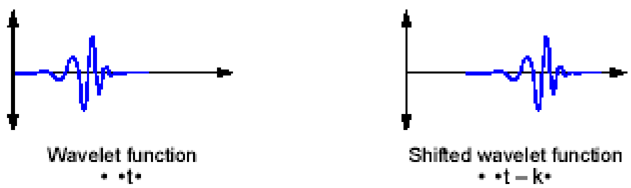


Figure 2-5

Scaling, as a mathematical operation, either dilates or compresses a signal. Larger scales correspond to dilated (or stretched out) signals and small scales correspond to compressed signals. *Scaling a wavelet simply means stretching (or compressing) it.* To go beyond colloquial descriptions such as "stretching," we introduce the scale factor, If we're talking about sinusoids, for example, the effect of the scale factor is very easy to see:



Shifting a wavelet simply means delaying (or hastening) its onset. Mathematically, delaying a function by k is represented by f t - k:



2.5 The Continuous Wavelet Transform

The continuous wavelet transform was developed as an alternative approach to the short time Fourier transforms to overcome the resolution problem. The continuous wavelet transform is defined as follows:-

$$CWT_x^{\psi}(\tau, s) = \Psi_x^{\psi}(\tau, s) = \frac{1}{\sqrt{|s|}} \int x(t)\psi^* \left(\frac{t-\tau}{s}\right) dt$$

As seen in the above equation, the transformed signal is a function of two variables, tau and s, the translation and scale parameters, respectively. psi(t) is the transforming function, and it is called the mother wavelet . The term mother wavelet gets its name due to two important properties of the wavelet analysis as explained below:

The term translation is used in the same sense as it was used in the STFT; it is related to the location of the window, as the window is shifted through the signal. This term, obviously, corresponds to time information in the transform domain. However, we do not have a frequency parameter, as we had before for the STFT. Instead, we have scale parameter which is defined as 1/frequency. The term frequency is reserved for the STFT.

Fortunately in practical applications, low scales (high frequencies) do not last for the entire duration of the signal, unlike those shown in the figure, but they usually appear from time to time as short bursts, or spikes. High scales (low frequencies) usually last for the entire duration of the signal.

All of the signals given in the figure are derived from the same cosine signal, i.e., they are dilated or compressed versions of the same function. In the above figure, s=0.05 is the smallest scale, and s=1 is the largest scale. In terms of mathematical functions, if f(t) is a given function f(st) corresponds to a contracted (compressed) version of f(t) if $s > 1$ and to an expanded (dilated) version of f(t) if $s < 1$.

However, in the definition of the wavelet transform, the scaling term is used in the denominator, and therefore, the opposite of the above statements holds, i.e., scales $s > 1$ dilates the signals whereas scales $s < 1$, compresses the signal. This interpretation of scale will be used throughout this text.

2.6 Computation of the CWT

Let x(t) is the signal to be analyzed. The mother wavelet is chosen to serve as a prototype for all windows in the process. All the windows that are used are the dilated (or compressed) and shifted versions of the mother wavelet. There are number of functions that are used for this purpose. The Morlet wavelet and the Mexican hat function are two candidates.

Once the mother wavelet is chosen the computation starts with s=1 and the continuous wavelet transform is computed for all values of s, smaller and larger than ``1''. However, depending on the signal, a complete transform is usually not necessary. For all practical purposes, the signals are band limited, and therefore, computation of the transform for a limited interval of scales is usually adequate. For convenience, the procedure will be started from scale s=1 and will continue for the increasing values of s , i.e., the analysis will start from high frequencies and proceed towards low frequencies. This first value of s will correspond to the most compressed wavelet. As the value of s is increased, the wavelet will dilate.

The wavelet is placed at the beginning of the signal at the point which corresponds to time=0. The wavelet function at scale ``1'' is multiplied by the signal and then integrated over all times. The result of the integration is then multiplied by the constant number 1/sqrt{s}. This multiplication is for energy normalization purposes so that the transformed signal will have the same energy at every scale. The final result is the value of the transformation, i.e., the value of the continuous wavelet transform at time zero and scale s=1 . In other words, it is the value that corresponds to the point tau =0 , s=1 in the time-scale plane. The wavelet at scale s=1 is then shifted towards the right by tau amount to the location t=tau , and the above equation is computed to get the transform value at t=tau , s=1 in the time-frequency plane. This procedure is repeated until the wavelet reaches the end of the signal. One row of points on the time-scale plane for the scale s=1 is now completed. Then, s is increased by a small value. Note that, this is a continuous transform, and therefore, both tau and s must be incremented continuously. However, if this transform needs to be computed by a computer, then both parameters are increased by a sufficiently small step size.

This corresponds to sampling the time-scale plane. The above procedure is repeated for every value of s. Every computation for a given value of s fills the corresponding single row of the time-scale plane. When the process is completed for all desired values of s, the CWT of the signal has been calculated.

The figures below illustrate the entire process step by step.

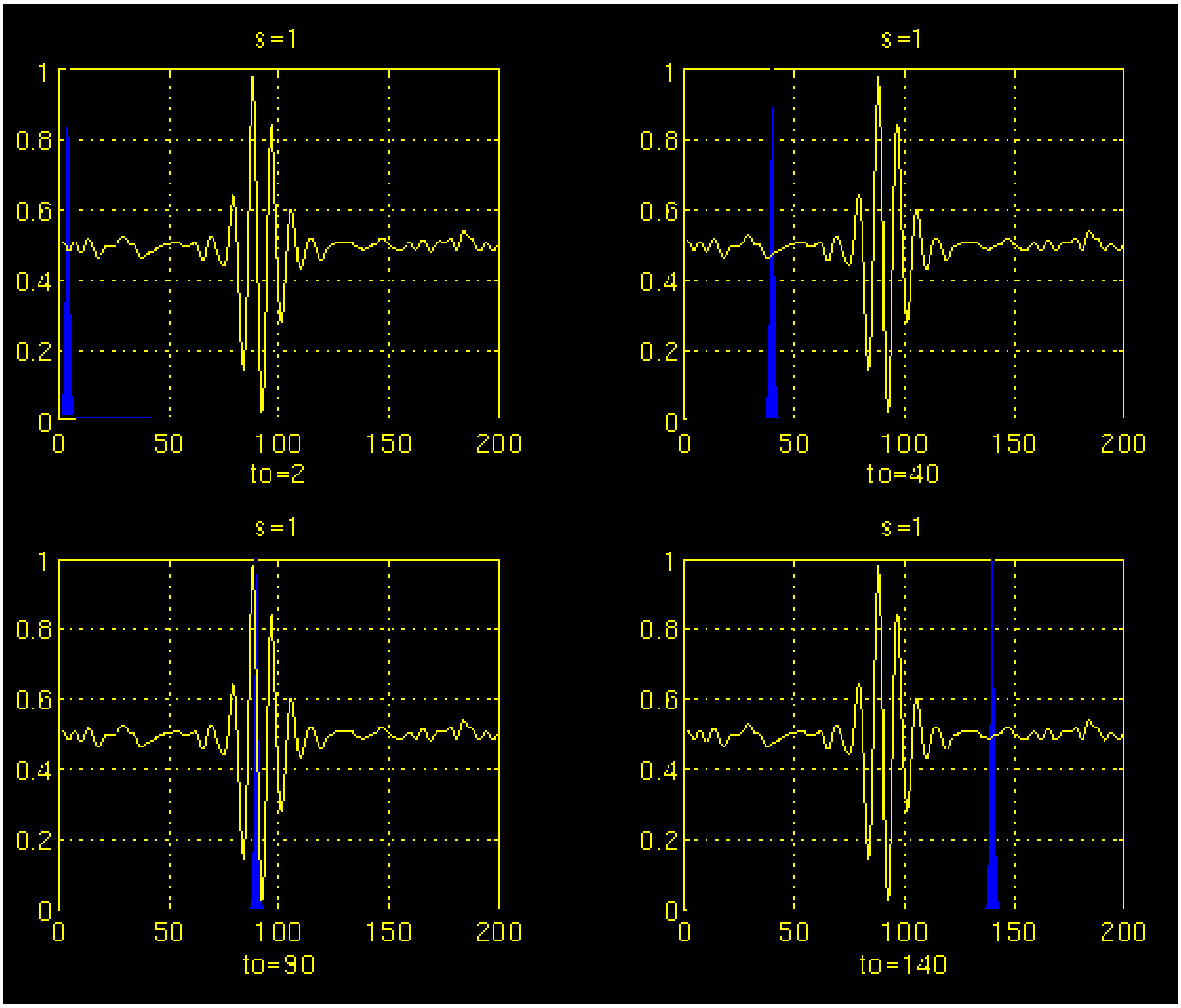


Figure 2-6

In Figure 2-6, the signal and the wavelet function are shown for four different values of tau. The scale value is 1, corresponding to the lowest scale, or highest frequency. Note how compact it is (the blue window). It should be as narrow as the highest frequency component that exists in the signal. Four distinct locations of the wavelet function are shown in the figure at to=2 , to=40, to=90, and to=140 . At every location, it is multiplied by the signal. Obviously, the product is nonzero only where the signal falls in the region of support of the wavelet, and it is zero elsewhere. By shifting the wavelet in time, the signal is localized in time, and by changing the value of s, the signal is localized in scale (frequency).

If the signal has a spectral component that corresponds to the current value of s (which is 1 in this case), the product of the wavelet with the signal at the location where this spectral component exists gives a relatively large value. If the spectral component that corresponds to the current value of s is not present in the signal, the product value will be relatively small, or zero. The signal in Figure 2-6 has spectral components comparable to the window's width at s=1 around t=100 ms.

The continuous wavelet transform of the signal in Figure 2-6 will yield large values for low scales around time 100 ms, and small values elsewhere. For high scales, on the other hand, the continuous wavelet transform will give large values for almost the entire duration of the signal, since low frequencies exist at all times.

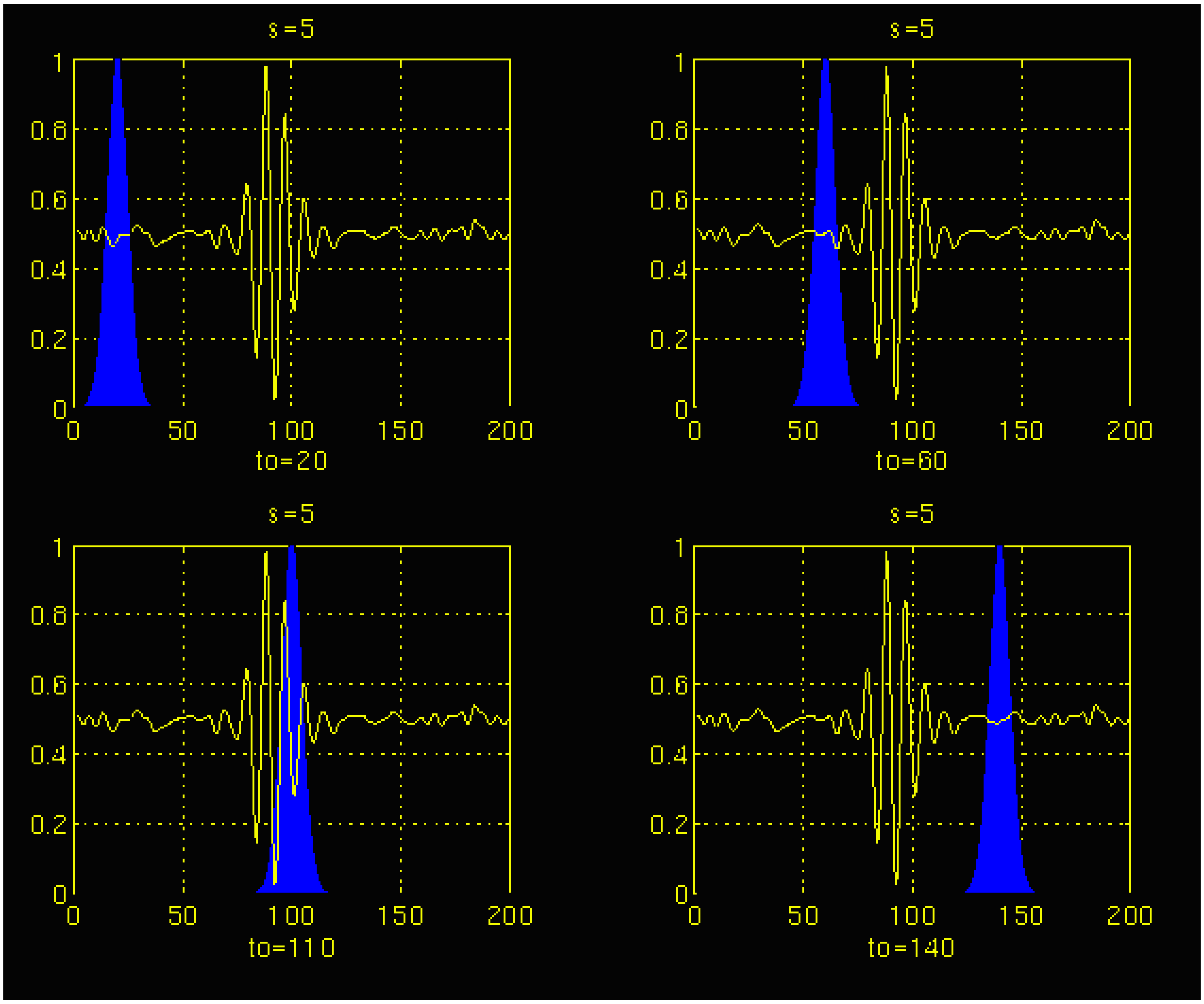


Figure 2-7

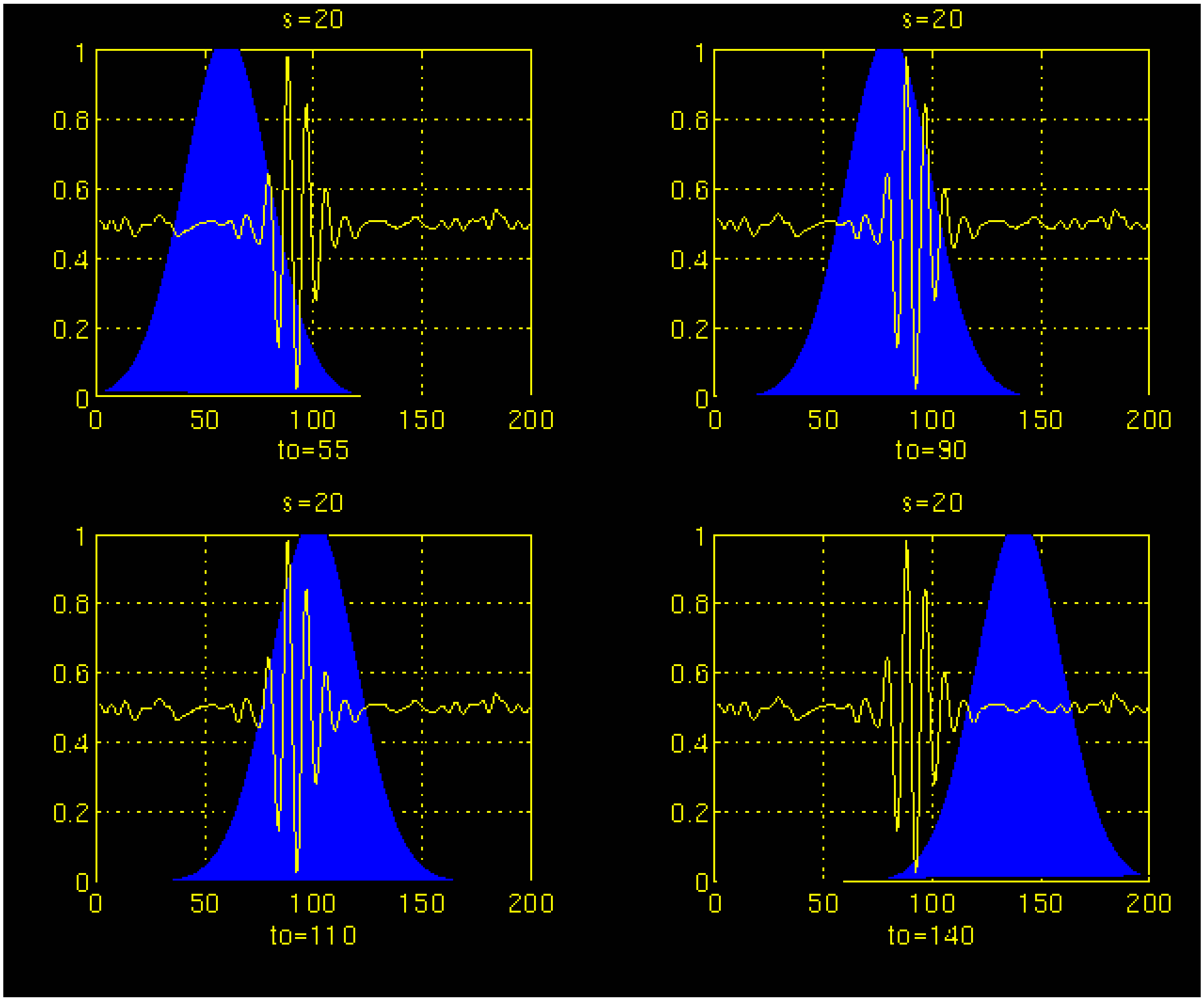


Figure 2-8

Figures 2.7 and 2.8 illustrate the same process for the scales s=5 and s=20, respectively. Note how the window width changes with increasing scale (decreasing frequency). As the window width increases, the transform starts picking up the lower frequency components.

As a result, for every scale and for every time (interval), one point of the time-scale plane is computed. The computations at one scale construct the rows of the time-scale plane, and the computations at different scales construct the columns of the time-scale plane.

Now, with the help of an example, we have tried to explain wavelet transform. Consider the non-stationary signal in Figure 2-9. This is similar to the example given for the STFT, except at different frequencies. As stated on the figure, the signal is composed of four frequency components at 30 Hz, 20 Hz, 10 Hz and 5 Hz.

Figure 2-9

Figure 2-10 is the continuous wavelet transform (CWT) of this signal. Note that the axes are translation and scale, not time and frequency. However, translation is strictly related to time, since it indicates where the mother wavelet is located. The translation of the mother wavelet can be thought of as the time elapsed since t=0. The scale, however, has a whole different story. Remember that the scale is actually inverse of frequency. In other words, whatever we said about the properties of the wavelet transform regarding the frequency resolution, inverse of it will appear on the figures showing the WT of the time-domain signal.

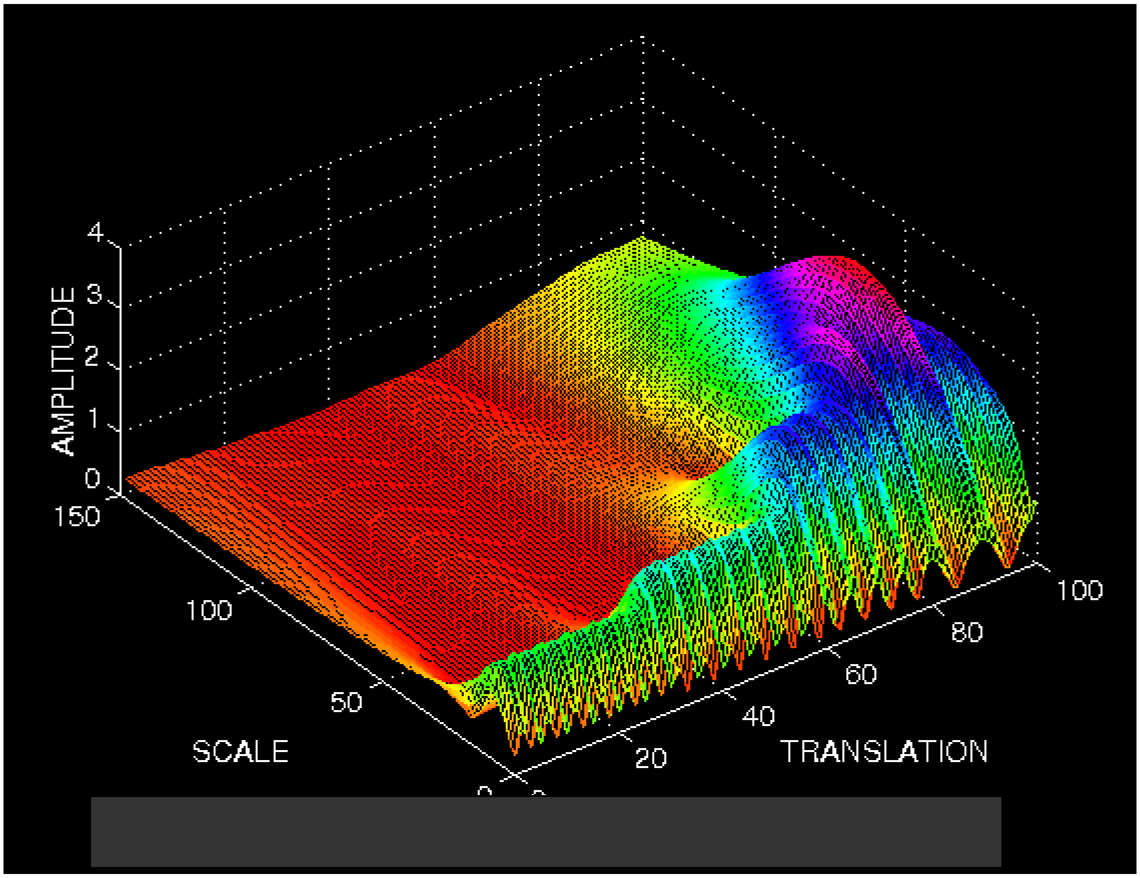


Figure 2-10

Note that in Figure 2-10 that smaller scales correspond to higher frequencies, i.e., frequency decreases as scale increases, therefore, that portion of the graph with scales around zero, actually correspond to highest frequencies in the analysis, and that with high scales correspond to lowest frequencies. Remember that the signal had 30 Hz (highest frequency) components first, and this appears at the lowest scale at translations of 0 to 30. Then comes the 20 Hz component, second highest frequency, and so on. The 5 Hz component appears at the end of the translation axis (as expected), and at higher scales (lower frequencies) again as expected.

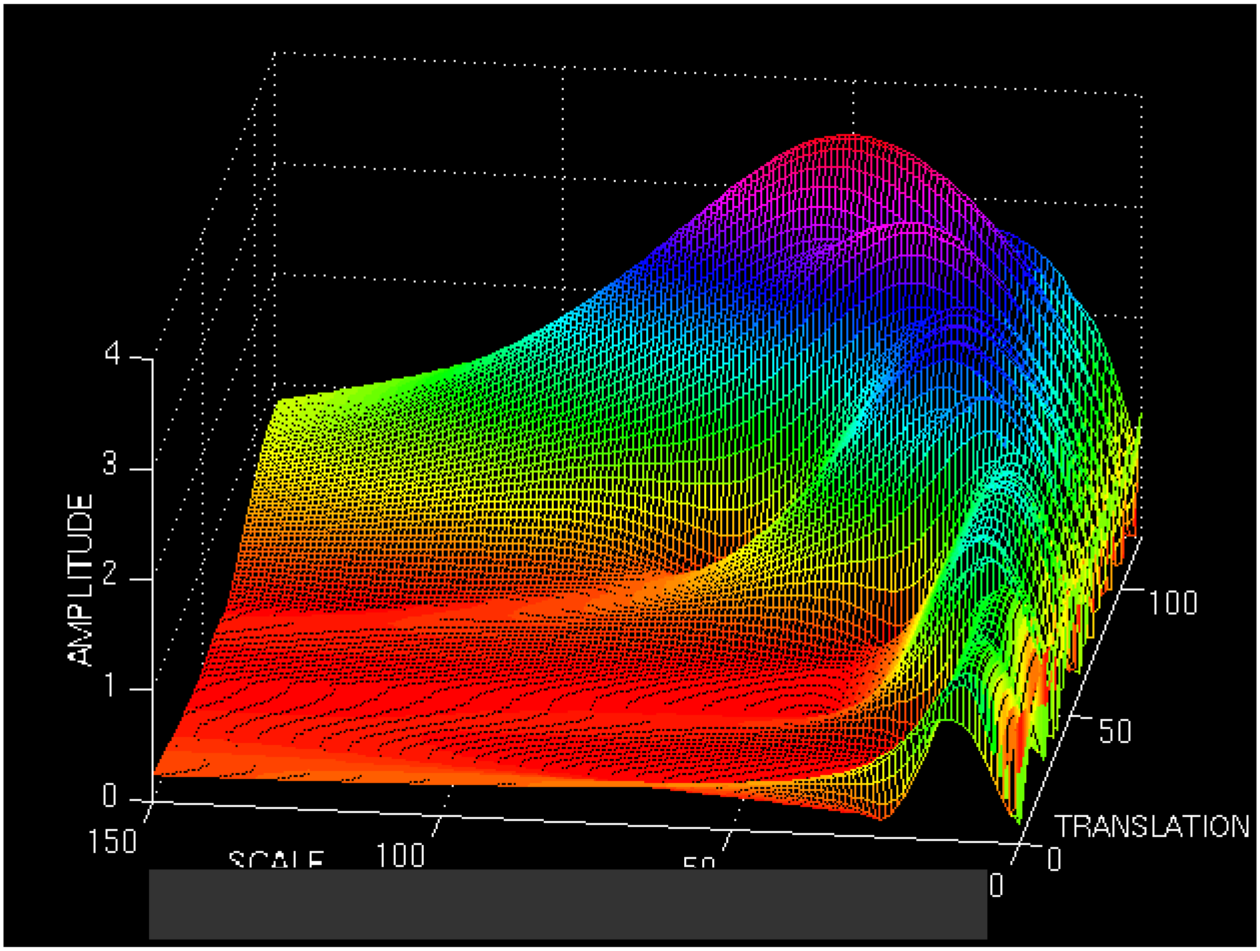


Figure 2-11

Now, recall these resolution properties. Unlike the STFT which has a constant resolution at all times and frequencies, the *WT has a good time and poor frequency resolution at high frequencies, and good frequency and poor time resolution at low frequencies.* Figure 2-11 shows the same WT in Figure 2-10 from another angle to better illustrate the resolution properties: In Figure 2-11 lower scales (higher frequencies) have better scale resolution (narrower in scale, which means that it is less ambiguous what the exact value of the scale) which correspond to poorer frequency resolution . Similarly, higher scales have scale frequency resolution (wider support in scale, which means it is more ambitious what the exact value of the scale is), which correspond to better frequency resolution of lower frequencies.

The axes in Figure 2-10 and 2.11 are normalized and should be evaluated accordingly. Roughly speaking the 100 points in the translation axis correspond to 1000 ms, and the 150 points on the scale axis correspond to a frequency band of 40 Hz (the numbers on the translation and scale axis do not correspond to seconds and Hz, respectively , they are just the number of samples in the computation).

2.7 Time and Frequency Resolutions

In this section we will take a closer look at the resolution properties of the wavelet transform. Remember that the resolution problem was the main reason why we switched from STFT to WT. The illustration in Figure 2-12 is commonly used to explain how time and frequency resolutions should be interpreted. Every box in Figure 2-12 corresponds to a value of the wavelet transform in the time-frequency plane. Note that boxes have a certain non-zero area, which implies that the value of a particular point in the time-frequency plane cannot be known. All the points in the time-frequency plane that falls into a box is represented by one value of the WT.

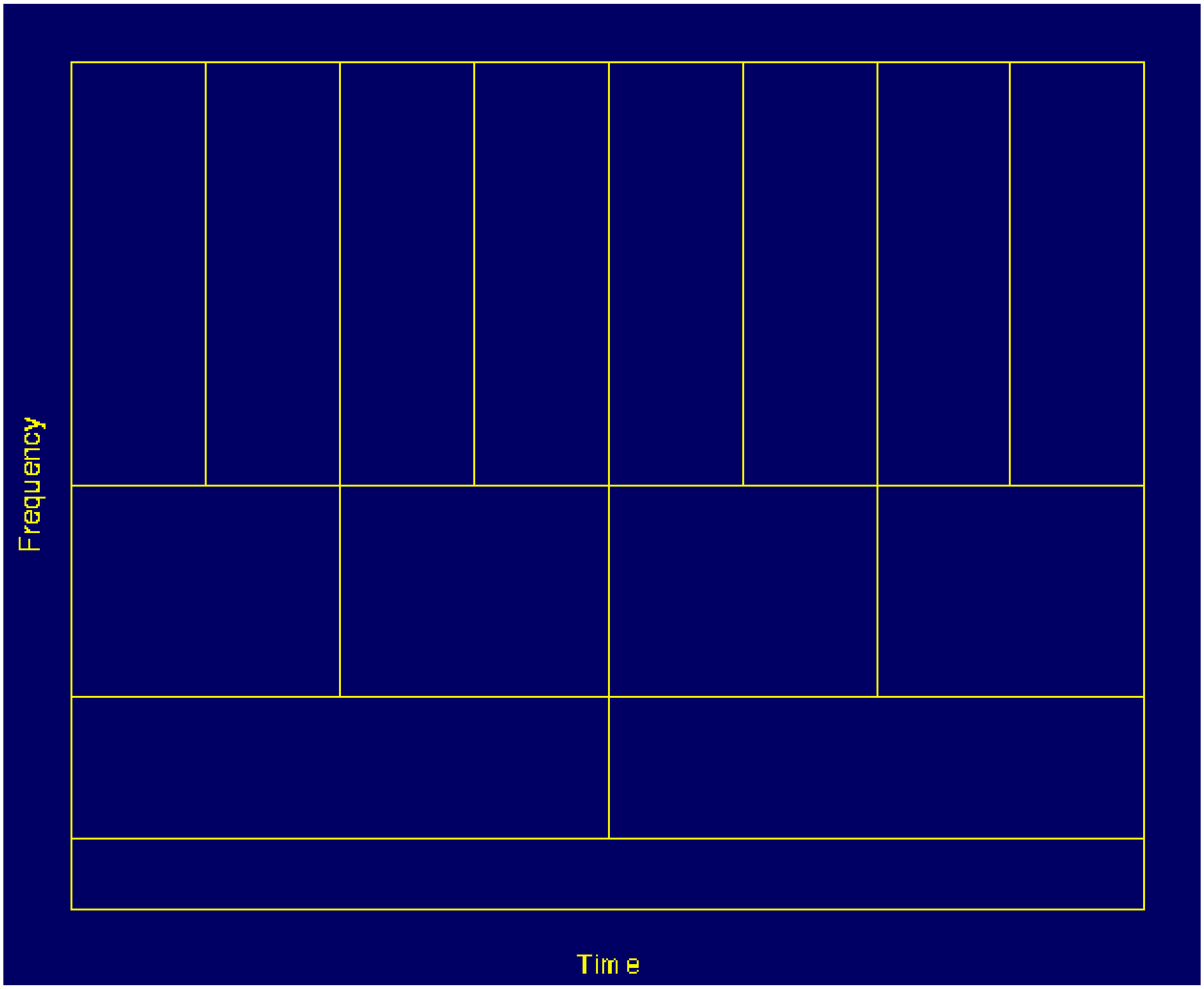


Figure 2-12

First thing to notice is that although the widths and heights of the boxes change, the area is constant. That is each box represents an equal portion of the time-frequency plane, but giving different proportions to time and frequency. Note that at low frequencies, the height of the boxes are shorter (which corresponds to better frequency resolutions, since there is less ambiguity regarding the value of the exact frequency), but their widths are longer (which correspond to poor time resolution, since there is more ambiguity regarding the value of the exact time). At higher frequencies the width of the boxes decreases, i.e., the time resolution gets better, and the heights of the boxes increase, i.e., the frequency resolution gets poorer.

Before concluding this section, it is worthwhile to mention how the partition looks like in the case of STFT. Recall that in STFT the time and frequency resolutions are determined by the width of the analysis window, which is selected once for the entire analysis i.e., both time and frequency resolutions are constant. Therefore the time-frequency plane consists of **squares** in the STFT case.

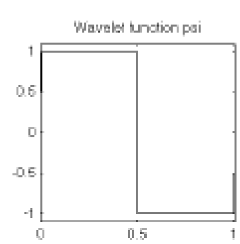
Regardless of the dimensions of the boxes, the areas of all boxes, both in STFT and WT, are the same and determined by **Heisenberg's inequality.** As a summary, the area of a box is fixed for each window function (STFT) or mother wavelet (CWT), whereas different windows or mother wavelets can result in different areas. We cannot reduce the areas of the boxes as much as we want due to the Heisenberg's uncertainty principle. On the other hand, for a given mother wavelet the dimensions of the boxes can be changed, while keeping the area same. This is exactly what wavelet transform does.

2.8 WAVELET FAMILIES

There are different types of wavelet families whose qualities vary according to several criteria.

- ***HAAR***

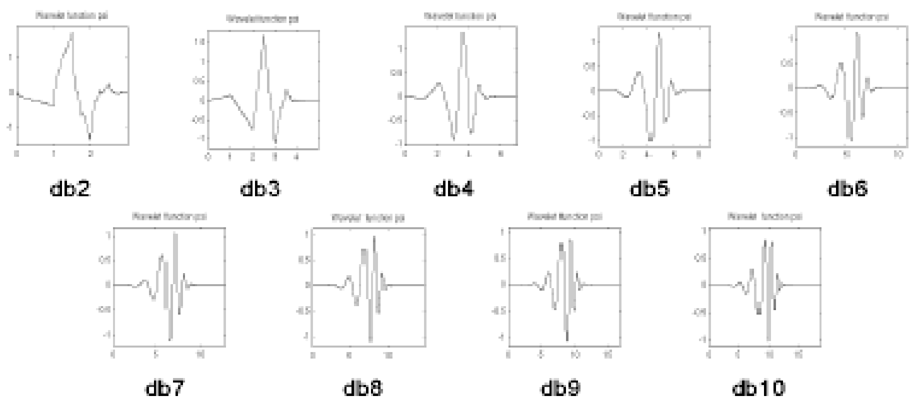
Any discussion of wavelets begins with Haar, the first and simplest. Haar is discontinuous, and resembles a step function. It represents the same wavelet as Daubechies db1.



DAUBECHIES

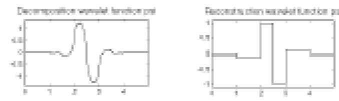
Ingrid Daubechies, one of the brightest stars in the world of wavelet research, invented what are called compactly-supported orthonormal wavelets — thus making discrete wavelet analysis practicable.

The names of the Daubechies family wavelets are written dbN, where N is the order, and db the “surname” of the wavelet. The db1 wavelet, as mentioned above, is the same as Haar. Here are the next nine members of the family:

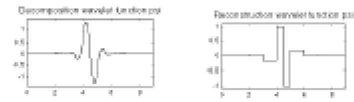


BIORTHOGONAL

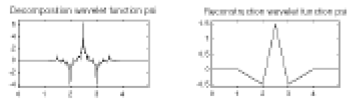
This family of wavelets exhibits the property of linear phase, which is needed for signal and image reconstruction. By using two wavelets, one for decomposition and the other for reconstruction instead of the same single one, interesting properties are derived.



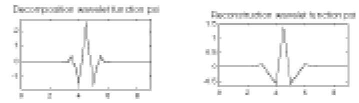
bior1.3



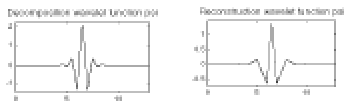
bior1.5



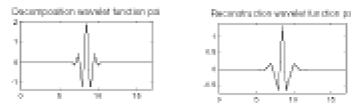
bior2.2



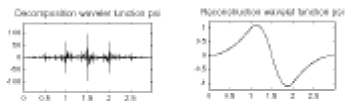
bior2.4



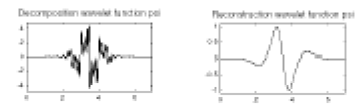
bior2.6



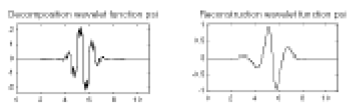
bior2.8



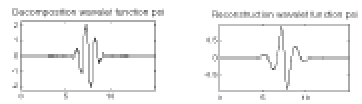
bior3.1



bior3.3

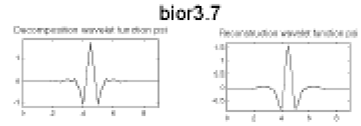


bior3.5

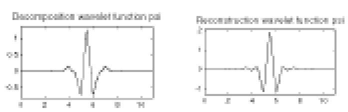


bior3.7

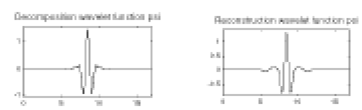
bior3.9



bior4.4



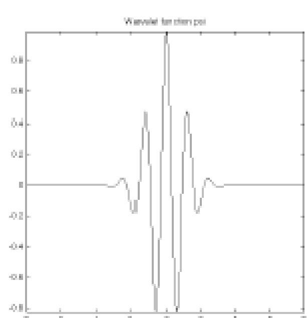
bior5.5



bior6.8

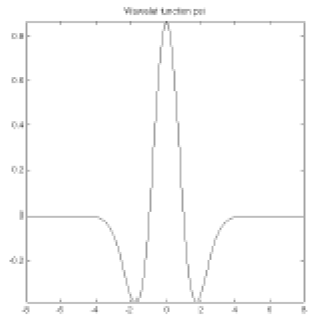
- ***MORLET***

This wavelet has no scaling function, but is explicit.



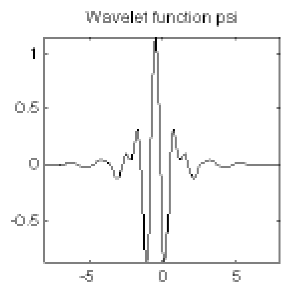
- ***MEXICAN HAT***

This wavelet has no scaling function and is derived from a function that is proportional to the second derivative function of the Gaussian probability density function.



- ***MEYER***

The Meyer wavelet and scaling function are defined in the frequency domain.



3 Design and Implementation of Algorithms

3.1 Quality Parameters

The results are expressed in the quality parameters Sensitivity, Specificity, Positive Predictivity and Accuracy.

Furthermore, we investigated the calculation time of the different algorithms.

- *Sensitivity* is the ability (probability) to detect ventricular tachyarrhythmia.

$$\frac{\text{detected cases of VT}}{\text{all cases of VT}} = \frac{TP}{TP + FN}$$

- *Specificity* is the probability to identify "no VT" correctly.

$$\frac{\text{detected cases of "no VT"}}{\text{all cases of "no VT"}} = \frac{TN}{TN + FP}$$

- *Positive Predictivity* is the probability, that classified VT is really VT:

$$\frac{\text{detected cases of "VT"}}{\text{all cases classified by the algorithm as "VT"}} = \frac{TP}{TP + FP}$$

- *Accuracy* is the probability to obtain a correct decision.

$$\frac{\text{all true decisions of "VT" and "no VT"}}{\text{all decisions}} = \frac{TP + TN}{TP + FP + TN + FN}$$

The quality parameters are obtained by comparing the decisions suggested by the algorithm with the annotated decisions suggested by cardiologists. The cardiologists' decisions are considered as true. We distinguish only between ventricular fibrillation and no ventricular fibrillation, since the annotations in the used data banks do not include a differentiation between ventricular fibrillation and ventricular tachycardia. The closer the quality parameters are to 1, the better the algorithm works.

To represent the quality of an algorithm by its sensitivity and specificity bears some problems. A special algorithm can have a high sensitivity, but a not so high specificity, whereas another algorithm can have a high specificity, but a not so high sensitivity.

Which one is better? To come to a common and single quality parameter, the critical parameters can be investigated.

To gain insight into the quality of algorithms for ECG analysis, it is essential to test the algorithms under equal conditions with a large amount of data, which are already commented by qualified cardiologists. We used the complete BIHMIT and CU data banks, and the files 7001 - 8210 of the AHA data bank No preselection of certain ECG episodes was made since this equals the situation of a bystander more accurately.

The parameters generally used to describe the reliability of fibrillation detection algorithms are their sensitivity and specificity. These values should be 1 in the ideal case and should not differ much in an AED application. Since the annotation of ECG data may not always be completely correct, experienced cardiologists should inspect the discrepancies between the results of the analysis and the annotations of the data in order to ascertain whether the results of the algorithm are perhaps also justified.

3.2 Process used in all implemented algorithms

In this thesis, we use the same procedure when testing different algorithms.

This is important to make the different methods comparable.

(1) The process in the algorithm reads the data according to the specified window length and signal time. In an AED application, the window length has to be specified as well.

(2) A signal modification is carried out to simulate real applications. This includes an optional adding of artificial CPR, noise and external mains electricity fields.

(3) A preprocessing is carried out. This includes a filtering process and a CPR filter that can optionally be applied to the detection process.

(4) The analysis is performed. This is the main part of each algorithm and characterizes its behavior. Each algorithm uses another method.

(5) A storage or output of the results, i.e., the results are saved into a file and/or displayed on the screen.

All algorithms are implemented in MATLAB.

3.3 Techniques for the analysis

In accordance with the work domain, we apply our approach in three different categories:

- Time domain, where the method is filtering the signal.

- Frequency domain, using classical spectral analysis.
- Time-frequency space, based on Wavelet Transform.

3.4 Flowchart

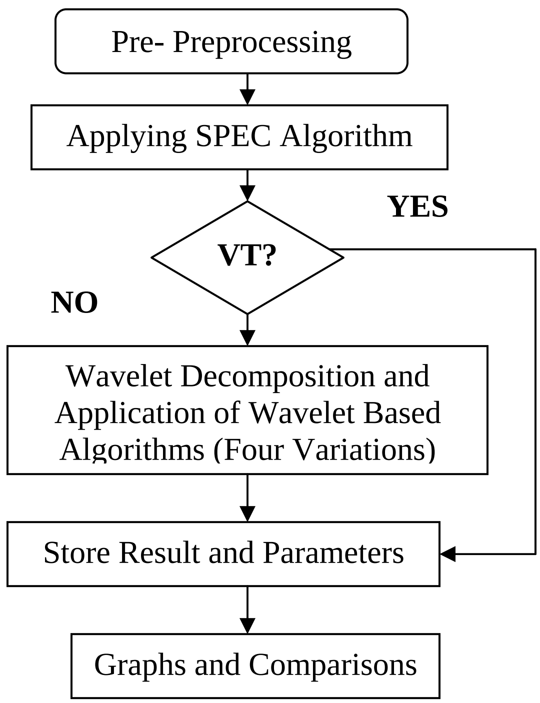


Figure 4-1: Flowchart

4.4.1 Preprocessing

This removes high frequency noise like interspersions and muscle noise.

4.4.2 Spectral Algorithm

The spectral algorithm (SPEC) works in the frequency domain and analyses the energy content in different frequency bands by means of Fourier analysis.

If VF is identified by SPEC algorithm we move on. In case if result of VF Detection is No, We provide an additional check to agree or disagree to the result. This is done to improve the sensitivity and accuracy.

4.4.3 Wavelet Decomposition

Wavelet coefficients are computed which reveal the hidden characteristics of ECG signals

4.4.4 Wavelet Based Algorithms

Four variations of wavelet based algorithms are implemented analyzing the input signal in time-frequency domain simultaneously.

4.4.5 Results

Entire set of MIT and CU database files were tested with VT detection system.

3.5 SPEC Algorithm

The spectral algorithm (SPEC) works in the frequency domain and analyses the energy content in different frequency bands by means of Fourier analysis. The ECG of most normal heart rhythms is a broadband signal with major harmonics up to about 25 Hz. During VF, the ECG becomes concentrated in a narrow band of frequencies between 4 and 7 Hz.

After preprocessing, each data segment is multiplied by a Hamming window and then the ECG signal is transformed into the frequency domain by fast Fourier transform (FFT). The amplitude is approximated in accordance with by the sum of the absolute value of the real and imaginary parts of the complex coefficients. Let Ω be the frequency of the component with the largest amplitude (called the peak frequency) in the range 0.5-9 Hz. Then frequencies with amplitudes whose value is less than 5 % of the amplitude of Ω are set to zero. Four spectrum parameters are calculated, the normalized first spectral moment M

$$M = \frac{1}{\Omega} \frac{\sum_{j=1}^{j_{max}} a_j \omega_j}{\sum_{j=1}^{j_{max}} a_j},$$

j_{max} being the index of the highest investigated frequency, and A_1,A_2,A_3.

Here w_j denotes the j-th frequency in the FFT between 0 Hz and the minimum of (20Ω, 100 Hz) and a_j is the corresponding amplitude. A_1 is the sum of amplitudes between 0.5 Hz and Ω /2, divided by the sum of amplitudes between 0.5 Hz and the minimum of

(20Ω, 100 Hz). A_2 is the sum of amplitudes between 0.7 Ω and 1.4 Ω divided by the sum of amplitudes between 0.5 Hz and the minimum of (20Ω, 100 Hz). A_3 is the sum of amplitudes in 0.6 Hz bands around the second to eighth harmonics (2Ω - 8Ω), divided by the sum of amplitudes in the range of 0.5 Hz to the minimum of (20Ω, 100 Hz).
VF is detected if M = 1.55, A_1 = 0.19, A_2 = 0.45, and A_3 = 0.09.

3.6 Wavelet Based Algorithm

3.6.1 Wavelet 0

First, a continuous wavelet transform (WT) of the ECG signal is carried out using a Mexican Hat wavelet as mother wavelet ψ_m,

$$\psi_m(t) = (1 - t^2) \exp(-t^2/2).$$

Then a Fourier transform is performed. Now, the maximum absolute values with respect to a are investigated in order to make the decisions for the defibrillation process.
However, one can show that this maximum values are located on a hyperbola in the (a, *w*) plane of the Fourier transform of the WT of the ECG signal, i.e. on a curve that has the representation a *w* = C, C being a constant. The values on this curve in the (a, *w*) plane are the FT of the ECG signal multiplied by a weight function y (*w*). Therefore, if one searches for the maximum values of L_ψ f in the (a, *w*) plane of the WT, it is sufficient to search for the maxima in the weighted FT of the ECG signal f (*w*).

3.6.2 Wavelet 1

In WVL1 this function is handled similar to the spectrum in the algorithm SPEC. First, each data segment is multiplied by a Hamming window and transformed into the frequency domain by fast Fourier transform (FFT). The result is multiplied by $1/(w)^{1/2}$. But only two parameters are calculated and thresholds for the decision are set. First, a threshold of 15% of the maximum value of the FFT signal is chosen. All signal parts below this threshold are set to zero. Afterwards A_1 and A_2 are calculated. A_1 is the maximum amplitude of the FFT between 0.5 Hz and 3.5 Hz. A_2 is the maximum amplitude of the FFT between 3.5 Hz and 20 Hz. If the ratio A_1/A_3 is smaller than 1.5, VF is detected.

3.6.3 Wavelet 2

WVL2 is a slight modification of WVL1. Each data segment is multiplied by a Hamming window and transformed into the frequency domain by fast Fourier transform (FFT). The result is squared (so the energy distribution is observed).

Also here, the result is multiplied by $1/ (w)^{1/2}$ .Three parameters A_1, A_2 and A_3 are calculated. A_1 is the energy content of the ECG signal between 0.5 Hz and 3.5 Hz, A_2 is the energy content of the ECG signal between 3.5 Hz and 9 Hz, and A_3 is the energy content of the ECG signal between 9 Hz and 50 Hz. If $(A_1 + A_3)/A_2$ is smaller than 0.5, VF is detected.

3.6.4 Wavelet 3

In WVL3 the function $1/ (w)^{1/2} * f (w)$ is handled exactly like the spectrum in the algorithm SPEC. The same spectrum parameters are calculated and also the thresholds for the decision, A_1, A_2, A_3, M, have the same values like the algorithm in SPEC. Mother Wavelet is HAAR Wavelet.

Chapter 4

4 VT Detection System

4.1 Introduction

VT Detection System is a System for doctors that are aimed at getting highly sensitive and accurate results for detection. This system is also capable if storing a patient's information as well as doctor's prescription for every beat of ECG data. Apart from that a very specialized feature of our system is input and output is in .dat files so that they can be reused. VT Detection system comprises of a very user friendly interface and provides ease of use even to a layman. This venture is a brain child of an electro physiologist and was realized by young software engineers of Military College of Signals (NUST).

4.2 How to Use the Software

The software is highly user friendly providing inbuilt help regarding many topics. The buttons /menus provided give a comprehensive detail and functionality. The details of using the software is given in the user manual attached to the software main menu.]

4.3 Menus and Working

The software has a main menu with help about what is ECG, what is VT, what is this project, what is Wavelet Transform, Information and Data flow of this Project and the ECG ANALYZER (which performs the main analysis and detection of Ventricular Tachyarrhythmia).

4.4 Standard Settings

The contents of the package must be placed into a writeable directory. This directory also has to be added to the MATLAB path with the command"addpath". This package contains some c-programs, which have to be compiled into mex-files first. To do this, copy all c-files from the package into the MATLAB home directory. The name of the

MATLAB home directory can be found by typing "matlabroot" into the command window. Then compile the files with the command "mex filename.c". The result from this command is a mexfile, which can by carried out by MATLAB. Copy these files into the the directory, where the package is located. Then you can start the analysis.

4.5 Illustration of all Components of ECG ANALYZER:

- **Directory**

The text beside shows, which is the current directory from where the data should be read. The contents of this directory are shown in the left listbox. There are only shown subdirectories and files of type *.dat, *.bda and *.CMP, because only such files can be analyzed. Therefore, otherfiles are not interesting.

- **Change directory**

The text beside shows, which will be the current directory as soon as the input will be confirmed with "Enter". If the directory does not exist, this will be told the user. Changing the directory also changes the result directory.

- **Result directory**

The text beside shows, into which directory the results will be written. This directory can differ from the directory, from where the data are read. The contents of the result directory are shown in the right listbox.

- **Change result directory**

The text beside shows, which will be the current result directory, as soon as the input will be confirmed with "Enter". If the directory does not exist, this will be told the user. Changing this directory does not change the directory, from where the data are read.

- **Standard settings**

Pressing this button results in a setting of the analyzing parameters in the following way:

Starting time of data in seconds: 0,
Ending time of data in seconds: 12,
Window length in seconds: 8,
Time interval in seconds: 1,
None of the checkboxes (noise, draw ECG, draw single steps, only one channel per file) is activated.
The algorithm does not change. The list of the data to be analyzed also does not change. The standard setting can be applied to all algorithms and yield the most relevant results. Each second the last 8 seconds of the data are analyzed. There are not drawn any plots and no noise is added. If a data file consists of more than one channel, all are analyzed.

- **Available data**

This list box shows, which subdirectories and files of type *.dat, *.CMP and *.bda are contained in the current directory. By double clicking the *.dat-, *.CMP- or *.bda files in the list, they can be moved into the list beside to be analyzed afterwards.

- **Data to be analyzed**

This list box shows, which data will be analyzed when the algorithm is started. The data can be obtained by double clicking on the *.dat-, *.CMP- or *.bda- files in the left listbox. To remove files from the middle listbox, double click on them.

- **Result**

'This list box shows, which result files already exist.
During the analysis such result files are added stepwise.
A result file is structured as follows:
First, there stands an "E", then the name of the original file, e.g. "cu05", then a hint to the used algorithm, e.g. "jSP" for Barros spectral algorithm described in Jekovas paper. Finally the extension ".dat". Therefore, all in all for example "Ecu05jSP.dat".
The result file is a text file with a few columns.
The first column contains the time within the data file.
The time difference between two successive rows is just the

time interval. The last but one column contains the decision
of the algorithm:

0: Sinus rhythm, no fibrillation (SR),
1: Ventricular fibrillation (VF),
2: Ventricular tachycardia (VT),
-1: no decision,
-2: not available.

The columns in between contain calculated parameters of the analysis. Since each algorithm calculates different parameters, they are listed in the main menu item "algorithm".

The last column contains the desired values according to the annotation file *.atr(ANO). (32 means VF; this is important for the calculation of the quality parameters sensitivity and specificity.) Double clicking the entries in the right listbox creates a graphical illustration of the calculated results and of the decision and desired value according to the atrributes-file. The decision of the algorithm is illustrated by colored asterisks.

yellow: no decision, green: Sinus rhythm, do not defibrillate!
red: ventricular fibrillation, blue: ventricular tachycardia

- **Algorithm**

'Here the algorithm can be chosen. It is used to analyze the chosen data.
Details about the different algorithms can be found in the main menu item "algorithm".

- **Starting time of data in seconds**

'This entry defines the time, from which on the data is analyzed.

- **Ending time of data in seconds (-1: entire file is analyzed)**

'The chosen data is analyzed up to this entry in seconds. To analyze the entire file, the entry must be -1.

- **Window length in seconds**

Each algorithm requires a certain amount of data to yield a result. The window length defines the duration (in seconds), that is used within the data file to carry out a single calculation in the analysis. The standard value is 8 seconds.

Large window lengths cause long durations for the calculation, small window lengths cause inaccurate results.

Some algorithms cannot work with any window length.

Still the value should always be about 8 seconds.

For details look into the main menu item "algorithm"!

- **Time interval in seconds**

This number defines the "movement" of the analyzing window from one analysis to the other. To obtain an analyzing result every second, the time interval has to be 1, to obtain a result every 2 seconds, it has to be 2, and so on.

Very small time intervals result in a many calculations, very large time intervals result in small accuracies. The standard value for the time interval is 1.

- **Noise factor**

Artificial noise of a certain amount is added to the signal.

White noise (not band limited) is used, the amplitude of the noise is: noise factor * signal amplitude.

With this tool different kinds of artifacts can be somehow simulated (long electrical leads, bad contacts...).

- **Draw ECG**

A plot is drawn from every file that should be analyzed.

The number of plots is the same as the number of file that should be analyzed.

- **Draw single steps**

A plot is drawn after every single calculation of the analysis of every analyzed file. Every plot has a time range with the size of the window length.

In case of a large time range to be analyzed, many plots are produced. Therefore, this application is recommended only in the case of small episodes to be analyzed (like for example when using the standard settings, 12 s).

- **Only 1 channel per file**

Some files contain more than one channel.
Normally, an evaluation requires just a single signal.
Using this application it is possible to analyze only one channel per file.

- **Start**

Pressing this button starts the analysis with the defined parameters.

Attention: already existing result files are possibly replaced!

- **Stop, exit**

Pressing this button stops the analysis and terminates the ECG analyzing program.

- **Processing**

'he text shows, which file is processed in the moment.
"Press Start" means, that the analysis has not started yet.

- **CPR factor**

'Before the ECG signal is analyzed, an artificial CPR signal is added. The ratio from the maximal amplitude of the CPR signal to the maximal amplitude of the ECG signal is specified by the entry in this field.

- **Execute CPR filtering**

'If the signal contains CPR artifacts, it is advisable to filter these artifacts before running the actual analysis. This prefiltering is carried out with a CPR filter algorithm, which was written by Andreas Klotz from the University of Vienna.

4.6 Steps for General Analysis:

A typical analysis is carried out as follows:

1.) In the MATLAB command line type "mex -setup", enter, choose the intern C-compiler and confirm.

The C programs must be located in the MATLAB home directory, which can be found by typing "matlabroot" in the command window. The C programs have to be compiled and the compiled programs copied back to the package containing the other programs. The directory of the package also has to be added to the MATLAB path with the command "addpath".

2.) Choose the data directory (in the left listbox or type directly into the edit window).

3.) Choose the result directory (this is either the directory, from where the data is read, or another one, that has to be typed into the edit window.

4.) Transfer the data, that you want to analyze, from the left listbox into the middle one (by double clicking). Data files can be removed from the middle list box by double clicking.

5.) Choose parameters, set checkboxes, choose algorithm, and possibly use standard settings.

6.) Press start button.

7.) Double click on the result files to view the result and the computed parameters.

5 Testing and Results

5.1 Testing

Files from different Ventricular Tachyarrhythmia Databases have been exhaustively tested to evaluate the functioning of the Detection System.

The data sets were taken from the BIH-MIT data bank (48 files, 2 channels per file, each channel 1805 seconds long), the CU data bank (35 files, 1 channel per file, each channel 508 seconds long), and the AHA data bank (files 7001 - 8210, 40 files, 2 channels per file, each channel 1800 seconds long). From the BIH-MIT and AHA data bank we used both channels. Thus, the total number of tests per algorithm and window length is 2 · 48 · (1805-window length+1)+35 · (508-window length+1)+2 · 40 · (1800-window length+1). Hence, for a window length of 8s the number of decisions is 333 583.

5.2 Results

5.2.1 Algorithm Results

The individual data files have shown the results attached in Appendix A.

- Overall Results

Sensitivity	Specificity	Positive Predictivity	Accuracy
40%-50%	**90.8%**	**72%-86%**	**80%-95%***

Table 5-1

* depending upon noise in data

5.3 Graphs

The results of each algorithm are plotted as below:

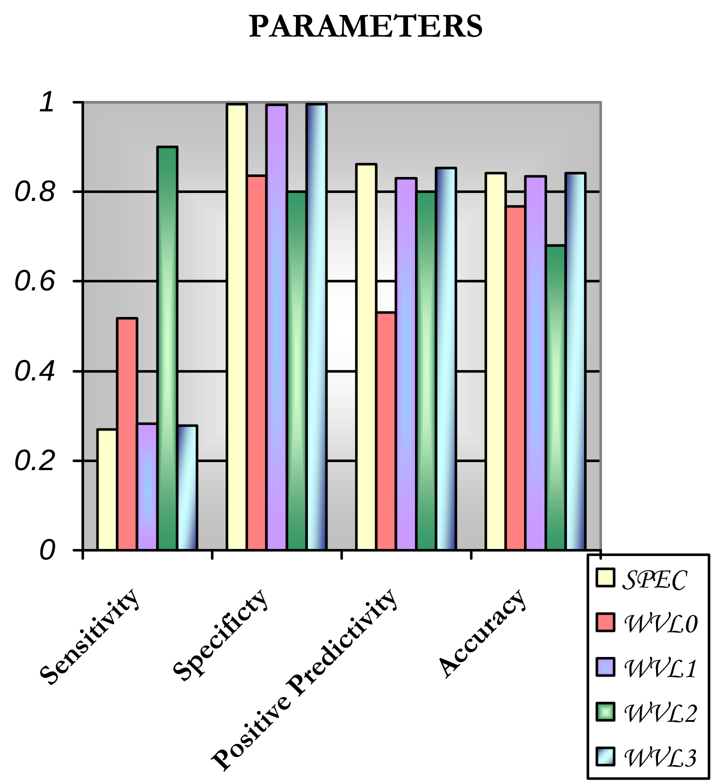


Figure 5-1: Algorithm Parameters Graphs

The time evaluations of the algorithms are given below:

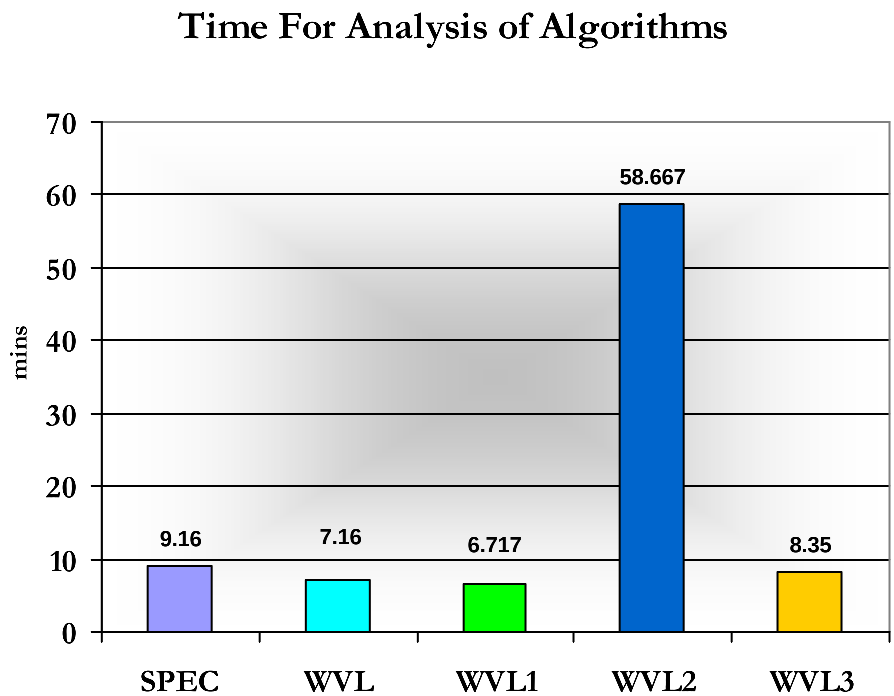


Figure 5-2: Time Analysis

5.4 Comparisons

Comparisons show that the VT Detection System is highly reliable as compared to most of the systems available.

Chapter 6

6 Conclusion and Future Work

6.1 Conclusion

VT detection System is first of its kind and the only system to perform beat to beat analysis for VT Detection. It enhances the sensitivity issue for VT detection. Higher level of accuracy achieved by this system is a milestone in filed of biomedical engineering. Enhanced features and user friendly interfaces offer all kinds of users a responsive system for VT detection. The proposed system overcomes the non-sensitivity of SPEC algorithm utilizing its highly specific nature to the fullest, enabling the cardiologists and electro physiologists to detect VT with accuracy of more than 85%. Thus the proposed system is highly reliable and efficient.

6.2 Future Work

Presently the system has generalized input as .dat files but it can also be generalized to accept any file format.

The analysis done in this thesis is for VT only. The system can be broadened to include all kinds of arrhythmias and make other ECG facilities embedded in one software product.

Hardware module can be designed and implemented for data acquisition. Features such as web service can also be initiated in it enabling end to end communication between cardiologists from different parts of the world share data and results.

APPENDIX A

RESULT TABLES

SPEC

Data	Sensitivity	Specificity	Positive Predictivity	Accuracy
cu01	0.973	1	1	0.984
cu02		0.97	0	0.97
cu03	0.442	0.996	0.905	0.948
cu04	0.327	0.987	0.967	0.629
cu05	0.575	0.99	0.926	0.918
cu06	0.197	1	1	0.78
cu07	0.248	1	1	0.511
cu08	0.207	1	1	0.87
cu09	0.298	0.998	0.944	0.918
cu10	0.359	1	1	0.754
cu11	0.314	1	1	0.812
cu12	0.155	0.997	0.968	0.671
cu13	0.204	1	1	0.914
cu14		0.996	0	0.996
cu15	0.301	1	1	0.856
cu16	0.054	1	1	0.788
cu17	0.487	1	1	0.96
cu18	0.296	0.996	0.8	0.958
cu19	0.395	0.99	0.895	0.888
cu20	0.072	1	1	0.511
cu21	0.488	0.995	0.969	0.864
cu22	0.027	1	1	0.786
cu23	0.157	1	1	0.828
cu24	0.206	0.998	0.933	0.89
cu25	0.231	1	1	0.94
cu26	0.095	0.97	0.35	0.84
cu27	0.13	0.998	0.75	0.958
cu28	0.333	0.988	0.4	0.972
cu29	0.115	1	1	0.77
cu30	0.054	1	1	0.295
cu31	0.0571	0.996	0.8	0.984
cu32	0.043	1	1	0.91
cu33	0.591	1	1	0.928
cu34	0.286	1	1	0.92
cu35	0.16	0.994	0.571	0.952
AVERAGE:	**0.26900303**	**0.995971429**	**0.862228571**	**0.842085714**

WVL

Data	Sensitivity	Specificity	Positive Predictivity	Accuracy
cu01	0.99	1	1	0.994
cu02		0.95	0	0.95
cu03	0.907	0.858	0.375	0.862
cu04	0.29	0.686	0.523	0.471
cu05	1	0.732	0.439	0.778
cu06	0.584	1	1	0.886
cu07	0.479	0.177	0.52	0.373
cu08	0.378	0.971	0.721	0.874
cu09	0.491	1	1	0.942
cu10	0.792	0.528	0.51	0.629
cu11	0.387	1	1	0.832
cu12	0.5	0.993	0.98	0.802
cu13	0.574	0.389	0.102	0.409
cu14		0.92	0	0.92
cu15	0	1		0.794
cu16	0.982	0.424	0.329	0.549
cu17	0.513	0.745	0.145	0.727
cu18	0	0.968	0	0.916
cu19	0.5	0.113	0.105	0.18
cu20	0.076	0.996	0.952	0.511
cu21	0.504	0.817	0.489	0.737
cu22	0.873	0.928	0.774	0.916
cu23	0.647	0.99	0.943	0.92
cu24	0.971	0.982	0.892	0.98
cu25	0.385	0.584	0.072	0.569
cu26	0.757	0.967	0.8	0.936
cu27	0	0.803	0	0.766
cu28	0	0.916	0	0.894
cu29	0	0.981	0	0.727
cu30	0.083	1	1	0.317
cu31	1	0.971	0.5	0.972
cu32	0.936	0.996	0.957	0.99
cu33	0.83	0.981	0.901	0.954
cu34	0.518	0.998	0.967	0.944
cu35	0.12	0.889	0.054	0.85
AVERAGE:	**0.517181818**	**0.8358**	**0.530882353**	**0.767742857**

WVL1

Data	Sensitivity	Specificity	Positive Predictivity	Accuracy
cu01	0.667	1	1	0.804
cu02		0.976	0	0.976
cu03	0.256	1	1	0.936

cu04	0.158	0.974	0.878	0.531
cu05	0.632	0.957	0.753	0.9
cu06	0.073	1	1	0.747
cu07	0.344	1	1	0.573
cu08	0.171	0.998	0.933	0.862
cu09	0.175	0.998	0.909	0.904
cu10	0.146	1	1	0.673
cu11	0.307	1	1	0.81
cu12	0.021	0.997	0.8	0.619
cu13	0.278	1	1	0.922
cu14		0.996	0	0.996
cu15	0.631	0.995	0.97	0.92
cu16	0.545	1	1	0.898
cu17	0.462	1	1	0.958
cu18	0.296	1	1	0.962
cu19	0.535	0.986	0.885	0.908
cu20	0.042	0.949	0.478	0.471
cu21	0	1		0.743
cu22	0.045	1	1	0.79
cu23	0.225	1	1	0.842
cu24	0.426	1	1	0.922
cu25	0.282	1	1	0.944
cu26	0.284	0.991	0.84	0.886
cu27	0	0.99	0	0.944
cu28	0	0.99	0	0.966
cu29	0.4	1	1	0.844
cu30	0.019	1	1	0.269
cu31	0.571	1	1	0.988
cu32	0.383	1	1	0.942
cu33	0.114	1	1	0.844
cu34	0.286	0.991	0.8	0.912
cu35	0.56	1	1	0.978
AVERAGE:	**0.282848485**	**0.993942857**	**0.830764706**	**0.833828571**

WVL2

Data	Sensitivity	Specificity	Positive Predictivity	Accuracy
cu01	0.973	1	1	0.984
cu02		0.413	0	0.413
cu03	0.907	0.061	0.083	0.134
cu04	0.665	0.572	0.649	0.623
cu05	0.931	0.848	0.563	0.862
cu06	0.781	0.67	0.471	0.701
cu07	0.681	0.48	0.709	0.611
cu08	0.756	0.959	0.785	0.926
cu09	0.667	0.572	0.167	0.583
cu10	0.568	0.964	0.908	0.812
cu11	0.409	0.069	0.142	0.162

cu12	0.418	0.078	0.223	0.21
cu13	0.352	0.685	0.119	0.649
cu14		0.393	0	0.393
cu15	0.913	0.613	0.379	0.675
cu16	0.357	0.969	0.769	0.832
cu17	0.846	0.931	0.508	0.924
cu18	0.778	0.973	0.618	0.962
cu19	0.663	0.759	0.363	0.743
cu20	0.538	0.975	0.959	0.745
cu21	0.628	0.879	0.643	0.814
cu22	0.736	0.967	0.862	0.916
cu23	0.569	0.962	0.795	0.882
cu24	0.368	0.995	0.926	0.91
cu25	0.692	0.522	0.109	0.535
cu26	0.378	0.548	0.127	0.523
cu27	0.826	0.659	0.104	0.667
cu28	1	0.751	0.09	0.756
cu29	0.7	0.992	0.968	0.916
cu30	0.174	0.5	0.504	0.257
cu31	0.929	0.906	0.22	0.906
cu32	0.426	0.991	0.833	0.938
cu33	0.67	0.993	0.952	0.936
cu34	0.75	0.804	0.326	0.798
cu35	0.48	0.733	0.086	0.721
AVERAGE:	**0.652393939**	**0.7196**	**0.484571429**	**0.697685714**

WVL3

Data	Sensitivity	Specificity	Positive Predictivity	Accuracy
cu01	0.963	1	1	0.978
cu02		0.972	0	0.972
cu03	0.465	0.998	0.952	0.952
cu04	0.335	0.991	0.978	0.635
cu05	0.494	0.995	0.956	0.908
cu06	0.197	1	1	0.78
cu07	0.252	1	1	0.513
cu08	0.183	1	1	0.866
cu09	0.246	0.995	0.875	0.91
cu10	0.38	1	1	0.762
cu11	0.314	1	1	0.812
cu12	0.155	1	1	0.673
cu13	0.056	1	1	0.898
cu14		0.998	0	0.998
cu15	0.311	1	1	0.858
cu16	0.045	0.997	0.833	0.784

cu17	0.41	0.998	0.941	0.952
cu18	0.333	0.994	0.75	0.958
cu19	0.302	0.988	0.839	0.87
cu20	0.068	1	1	0.509
cu21	0.473	0.995	0.968	0.86
cu22	0.036	1	1	0.788
cu23	0.147	1	1	0.826
cu24	0.191	1	1	0.89
cu25	0.231	0.991	0.692	0.932
cu26	0.027	0.984	0.222	0.842
cu27	0.13	1	1	0.96
cu28	0.25	0.99	0.375	0.972
cu29	0.146	1	1	0.778
cu30	0.051	1	1	0.293
cu31	0.857	1	1	0.996
cu32	0.064	1	1	0.912
cu33	0.602	1	1	0.93
cu34	0.268	1	1	0.918
cu35	0.2	0.989	0.5	0.95
AVERAGE:	**0.278242424**	**0.996428571**	**0.853742857**	**0.841**

APPENDIX B

SYSTEM REQUIREMENT SPECIFICATION DOCUMENT

Ventricular Tachyarrhythmia Detection System

System Requirement Specification

Version (1.0)

VT DETECTION SYSTEM

Project Supervisor

- Brig Dr. Muhammad Akbar
  - Chief Instructor Military College of Signals

    (National University of Sciences and Technology).

Domain Expert (Medical)

- Brig. Dr. Imran Majeed

(HoD Clinical Cardiac Electrophysiology AFIC-NIHD)

Project Team

- Muazma Zahid (Project Leader)
- Sadaf Malik
- Umair Ahsan
- Capt Zahid Sultan

EXECUTIVE SUMMARY

Heart is an important organ in the human body. Its functioning depends upon two major aspects. The Physiological aspect which consists of the physical structure of the heart like atria, ventricles etc and the Electrophysiological aspect which consists of the Sino-Atrial (SA) Node and the Atrio-Ventricular (AV) Node along with the conduction paths i.e., His Bundles. The pumping of the heart takes place due to the electrical signals / impulses emanated by these electrical nodes. The electrical impulses polarize and depolarize the heat muscles causing contraction and relaxations.

Ventricular Tachyarrhythmia (VT) is responsible for 75 to 85% of sudden deaths in heart patients. The traditional ECG is normally based on 12 leads signal acquisition comprising of 4 limbs and 6 chest leads. The information rendered by this mechanism is usually insufficient in diagnosing / identifying VT. Another important factor that makes the ECG phenomena fall short is its time domain graphical representation but no frequency information.

Accurate and sensitive VT Detection system is required to help the cardiologists and electro physiologists treat the patients accordingly. However, the concept is quite new and almost no rudimentary or research work is available on it due to evident economic reasons. Therefore, the Project shall stand at the foundations of a Research Paper Compiled and Experimented initially in consultation with the Domain Expert. The facilities of the major Stakeholder and User shall of great help.

The project is undertaken as a degree project hence no cost factor is involved or needs to be negotiated.

OVERVIEW

The SRS includes a brief product perspective and a summary of the functions the software will provide. User characteristics are discussed and any general constraints or assumptions and dependencies are listed. A process diagram and various state diagrams are included.

INTRODUCTION

- **CONCEPT**

Heart is one of the most important organs in the human body. Its proper functioning (i.e., healthy habits) depends upon two phenomena:-

  - The Physiological structure of the heart i.e., the muscles and the physical structure of the heart
  - The Electrophysiological aspect i.e., the electrical conduction system around the heart.

In order to understand the project in its entirety it is essential to understand the structure and functioning of the heart to a reasonable degree.

- **The Heart**

Structure of the Heart

Human Heart is located between lungs in the middle of the chest, behind and slightly to the left of breastbone (sternum). A double-layered membrane called the pericardium surrounds the heart like a sac. The outer layer of the pericardium surrounds the roots of heart's major blood vessels and is attached by ligaments to the spinal column, diaphragm, and other parts of the body. The inner layer of the pericardium is attached to the heart muscle. A coating of fluid separates the two layers of membrane, letting the heart move as it beats, yet still be attached to the body.

The heart weighs between 7 and 15 ounces (200 to 425 grams) and is a little larger than the size of ones fist. By the end of a long life, a person's heart may have beaten (expanded and contracted) more than 3.5 billion times. In fact, each day, the average heart beats 100,000 times, pumping about 2,000 gallons (7,571 liters) of blood.

The heart has four chambers and few other parts as following:-

- **Atria**. The top two chambers that receive blood from the body or lungs.
- **Septum**. A wall of muscle called that separates the left and right atria and the left and right ventricles.
- **Ventricles**. The bottom two chambers. The right ventricle pumps blood to the lungs to pick up oxygen, the left ventricle is the largest and strongest chamber in the heart. The left ventricle's chamber walls are only about a half-inch thick, but they have enough force to push blood through the aortic valve and into the body.
- **Valves**. There are four valves in the heart that help to direct blood flow. As they open and close, the valves produce sounds that can be heard with a stethoscope. The heart sounds can often tell your doctor about your hearts function.

- **<u>The Electrical Conduction System</u>**

Electrical impulses from the heart muscle (the myocardium) cause heart to contract. This electrical signal begins in the sinoatrial (SA) node, located at the top of the right atrium. The SA node is sometimes called the heart's "natural pacemaker." An electrical impulse from this natural pacemaker travels through the muscle fibers of the atria and ventricles, causing them to contract. Although the SA node sends electrical impulses at a certain rate, the heart rate may still change depending on physical demands, stress, or hormonal factors.

The further propagation of the electrical impulse is through the Atrio-Ventricular (AV) node. Through which the impulse is first held for a while and then released to cause contraction of the Ventricles. The electrical impulse gets terminated at the Purkinje fibers.

- **Motivation**

  It is evident from the preceding discussion that to diagnose a Cardiac Disorder or Disease we need two kinds of perspectives to be looked at,

  - Firstly, the time and frequency domain of the ECG signal.
  - Secondly, the time-frequency localization simultaneously.

The information obtained through ECG is much less to establish the true perspective of the malfunctioning. This perspective (electrical) can be substantially enhanced if we apply Wavelet transform.

The perceived concept is likely to be of great help in the field of Electrophysiological Investigations thereby becoming one of the latest areas of research and development. The field is new and not much work is available. The research is on however is restricted to the market competitors in the field of bio medics due to its futuristic monitory value.

The project has sufficient inherent potentials to stand among one of the best projects in the field.

Definition of System

"To design and develop an Efficient, Accurate and Sensitive system in order to help the Cardiologists and Electro Physiologists for Detection of Ventricular Tachyarrhythmia (VT)".

Implicit Requirements of the Defined System

- **Calls for a comprehensive Research Work**. Since not much work has been done earlier on this project / methodology of applying wavelet transform for VT Detection. This shall serve both the ends,

  - Firstly, Clarification, Improvement and Translation of the conceptual schema of the project into technical terms through successive and progressive experimentation.

- Secondly, providing a base / referential blueprint for the development work on the system.

- **Need for Extensive Experimentation**. The research and development involves active and progressive experimentation. This experimentation is challenging due to a number of reasons namely,
  - Concept Evolution Experimentation at various stages of design.
  - Testing on the ECG data needs active involvement of the domain expert and the paraphernalia of the stakeholder i.e., AFIC / NIHD.
  - Validation of the developed / researched concepts and mathematical modeling.
  - Final testing and deployment of the system as working model.

➢ ***CHALLENGES***

o **Study of Related Human Anatomy and Electro Physiology**.

The electrical signals being produced at the human heart is a complex phenomenon itself falling under the medical Super Specialty of “Electro Physiology” a complex and rich field of study by itself. The design and development of the Detection system involves an in-depth understanding of the following phenomena:-

- Identification and Study of the ECG signal characteristics.
- The study of the Wavelet Transforms and their applications for ECG signals.
- All types of VT.
- A thorough understanding of the ECG, VT and how to compute parameters for algorithm evaluation.

GENERAL OVERVIEW

SYSTEM INPUTS

- **Signals**

.dat files from Holter Machines serve as input to VTDS.

MIT, CU and AHA database .dat files with associated header files are used to test the algorithm results.

OUTPUTS

- **Results**
    - All parameters results
    - Noise factor results

ALL FUNCTIONS

- **Signals Acquisition from Machine**
- **Noise Filtration**
- **Application of Algorithms**
- **Graphical User Interface (GUI)**
    - **Main Menu**
    - **ECG analyzer**
- **Results View**

PRODUCT FUNCTIONS

Software shall perform the following functions:

a) Provide Complete Help for each and every aspect of the Software

b) Acquire .dat files both online and offline

c) Analysis of ECG signal using a specific algorithms

d) Noise factor results calculation

e) Parameters results computation

USER CHARACTERISTICS

Following types of users shall interact with the system:

a) System Administrator

b) Engineers

c) Electro physiologists.

d) Cardiologist(s)

e) Technicians

f) Junior Clerks/ Data Entry Operators

Based on above type of users and their skills following precautions should be taken

1. The interfaces shall be designed keeping novice in mind.
2. Data entry masks should recognize and correct wrongly entered data.
3. Confirmation shall be asked from the user while deleting or changing a record
4. Error messages shall be used wherever required.
5. Users shall be consulted throughout design
6. Help option will be provided to all users.
7. Interfaces should be user friendly.

APPENDIX C

SOFTWARE DEVELOPMENT PLAN DOCUMENT

Ventricular Tachyarrhythmia Detection System

Software Development Plan

Version (1.0)

Preface

In this document the detailed development and management plan for VT Detection System is described. This plan will be strictly followed over a course of six months. Any modifications applied to this plan will be incorporated in the next versions of this document.

The document includes the details of the software to be delivered, major activities, major deliverables, major milestones, required resources, and top-level schedule and budget will be followed in the sections to come.

1. Introduction

This section contains the details of the project and the software product being to be built. In this section we give a brief overview of the project.

1.1 Project Overview

VT Detection System is a complete solution with tools that enables cardiologists and electro physiologists for accurate, specific and sensitive VT detection

1.1.1 Product Functions

VTDS is a multipurpose software kit, which performs various important functions; it provides the capability to perform VT detetcion. It has an integrated database of ECG recordings.

1.1.2 Minimum Requirements

The minimum requirement for the software to be operational requires Microsoft WINDOWS XP with MATLAB.

1.1.3 Major milestones

The major milestones of the project are

- Completion of Project Plan
- Completion of Requirement Analysis and Project Specifications phase.
- Completion of Design phase
- Implementation and Integration of components.
- Product testing, installation and approval

The details of the software to be delivered, major activities, major deliverables, major milestones, required resources, and top-level schedule and budget will be followed in the sections to come.

1.2 Project Deliverables

This section delineates the major items to be delivered to either the external customer or the in-house user. Following are the details:

1.2.1 List of Project Deliverables

List of project deliverable is as follows:

Deliverable Name	Due Date
1) Project Definition and List of team Members	15th MAY 2005
2) Project Plan	1st June 2005
3) Requirements Description	15th June 2005
4) Requirement Analysis	1st July 2005
5) Project Specifications	26th August 2005
6) Testing Plan	15th April 2006
7) Detail Design Document	20th April 2006
8) Fully Functional Product Model	15th April 2006
9) Project Report and Review	19th April 2006

Further deliverables will be provided upon request.

1.2.2 Details of the Deliverables

Following are brief details of the project deliverables

Project Definition and List of team Members

This includes definition of project and list of team members

Project Plan

This document describes how the team is to be structured and managed for the duration of the project.

Requirements Description

This document outlines the requirements of the proposed software system, upon which design and coding is based.

Requirement Analysis

A detailed analysis of user requirements based on requirements document.

Project Specifications

This document will describe detailed specification for VTDS defining parameters and interface.

Testing Plan

A complete testing plan describing how and when the testing will be carried out. This document describes the methodologies used in testing the system.

Detail Design Document

This document builds on the high-level design, and further details the specifics of Coding Product implementation and key algorithms as required.

Fully Functional Product Model

A fully functional product model will be demonstrated. A full source code will also be given if requested.

Project Report and Review

This will include complete project journal explaining what was achieved during the project. Also further improvements possible will also be described.

1.3 Evolution of the Software Project Management Plan

The project document is to be expected to evolve in the following manner over time. The following chart illustrates.

Version	Primary Author(s)	Description of Version	Date Expected
Draft	Vision Software Makers	Initial draft created for distribution and review comments	1st April, 2006
Preliminary	Vision Software Makers	Second draft incorporating initial review comments, distributed for final review	10th April, 2006
Final	Vision Software Makers	First complete draft, which is placed under change control	19th April, 2006
Revision 1	Vision Software Makers	Revised draft, revised according to the change control process and maintained under change control	25th April, 2006

Any modifications applied to this plan will be incorporated in the next versions of this document.

6.3 1.4 Reference Materials

Refer Appendix A

6.4 1.5 Definitions and Acronyms

Refer Appendix B

2. Project Organization

This section describes the development structure of the project which includes the process model (e.g., lifecycle model), the organizational structure (e.g., chain of command or management reporting structure), and responsibilities of individuals on the project.

2.1 Process Model

2.1.1 Project Life Cycle Model

VTDS will be developed using spiral life-cycle model. The model is as follows:

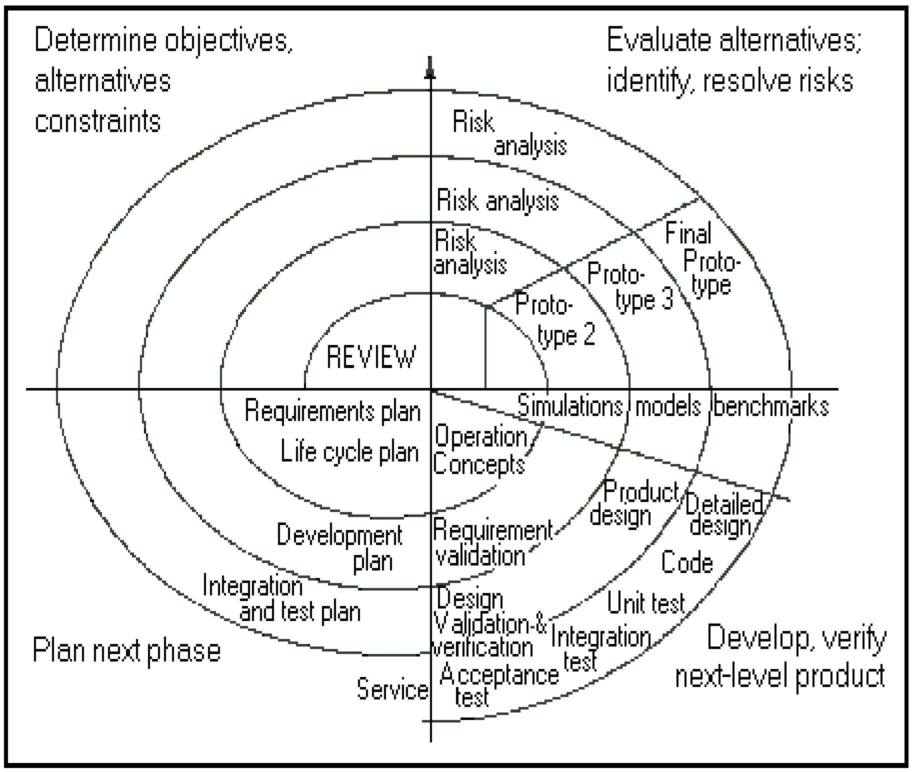


Fig. 1 Spiral Model

2.1.2 Significance

Incremental Model is best suited for VTDS as:

- The Spiral model is better from waterfall as it allows for risk management where the Waterfall places too much emphasis on project management
- The duration of the development period is 8-12 months for which this model is best suited.

- There are only four team members. So each and every member will have to participate in all the phases and deliverables
- Good for large and complex projects
- Customer Evaluation allows for any changes deemed necessary, or would allow for new technological advances to be used
- Allows customer and developer to determine and to react to risks at each evolutionary level
- Direct consideration of risks at all levels greatly reduces problems

2.1.3 Project Work Products

Following work products are listed for completion. Accompanying relevant details of due dates and concerned personnel is also listed:

Work Product Name	**Placed Under Change Control?**	**Deliverable to Customer?**	**People Who Must Sign Off on the Work Product**

REQUIREMENTS DESCRIPTION This document outlines the requirements of the proposed software system, upon which design and coding is based.	Yes	Yes	Project Manager, CEO, Requirements Engineer
REQUIREMENT ANALYSIS A detailed analysis of user requirements based on requirements document.	Yes	Yes	Project Manager, CEO, Requirements Engineer
PROJECT SPECIFICATIONS This document will describe detailed specification for DTS defining parameters and interface.	Yes	Yes	Project Manager, CEO, Requirements Engineer
TESTING PLAN A complete testing plan describing how and when the testing will be carried out. This document describes the methodologies used in testing the system.	Yes	Yes	Project Manager, Test Officer, CEO

DETAIL DESIGN DOCUMENT This document builds on the high-level design, and further details the specifics of Coding Product implementation and key algorithms as required. Also includes graphical representation model of the product.	Yes	No	Project Manager,CEO, Designer
Fully Functional Product Model A fully functional product model will be demonstrated. A full source code will also be given if requested.	Yes	Yes	Project Manager, CEO
PROJECT REPORT AND REVIEW This will include complete project journal explaining what was achieved during the project. Also further improvements possible will also be described.	Yes	Yes	Project Manager,CEO

2.2 Organizational Structure

2.2.1 Parent Organization

The personnel involved in this project are as follows:

- Muazma Zahid (Chief Executive Officer, Designer, User Interface Prototyper)
- Umair Ahsan (Chief Technical Officer)
- Capt Zahid Sultan (Customer Analyst, Chief Operational Officer)
- Sadaf Malik(Quality Assurance Manager, Chief Project Officer)

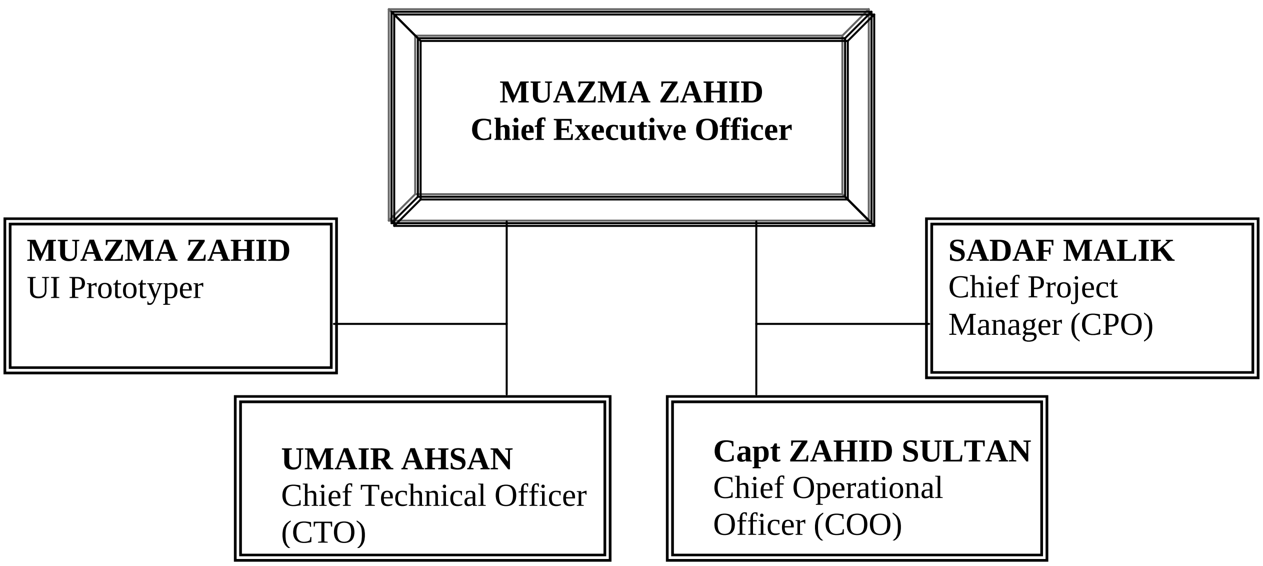


Fig. 2 Organization Chart of the Executive Staff

Each member is equipped with significant Computer Science, Mathematics and other skills acquired during education training to accomplish the project.

All are expected to contribute approximately equal amounts of work to the project on a weekly basis. This workload needs to be balanced with other subjects team members are undertaking. It is expected that a weekly workload for this project should be a minimum of approximately 20 **hours/week**.

2.2.2 Customer organization (external)

AFIC-NIHD being the external customer organization has been kept in linked to the project directly by the project manager.

2.3 Organizational Boundaries and Interfaces

- Regular meetings with client will be held. The project progress will have to be approved by the client at least once a week. Explanation of different requirements will be acquired from the client.
- Any member of the team will not reveal the project documentation to any party other than the client.
- Also every member will have to attend team meetings unless he/she has a valid reason. Team members will meet at least twice a week and a detailed meeting will be held before submission of each deliverable.

Informal Communication will also be used extensively in this project due to its quick and efficient information transferal properties. The team utilizes personal communication and email communication (somewhat formal in nature given that they are archived) as much as possible. While it is difficult to always meet with the other team members required (given their varying academic timetables), personal communication is preferred over email communication for its instantaneous feedback. However, given these academic restrictions, email communication is used as the primary form of interacting with other team members. Email communication also affords a form of trace ability that other informal mechanisms fail to provide.

- The Project is directly communicating with the upper management of the organization as it is the key project at hand.
- Project Manager will be responsible for communicating with the upper management.
- Direct communication is being held and will be held with the Customer

organization externally.

- Again the Project manager will be responsible for communication with the customer organization.
- There are no subcontracting organization(s) associated with project.
- There are no other organizations that the project interacts with. Any future interactions or relationship will be delineated in the future revised versions of the document if the need arises.
- This project is completely independent of the other projects that the organization is dealing with. Currently this project and its completion remain the top priority of Vision Software Makers. All other projects have been halted for the time being to give utmost time and resources to this project currently at hand.

2.4 Project Responsibilities

The following chart illustrates the persons and their respective responsibilities concerning this project. Any changes in the given structure will be incorporated in the future versions of the document.

Responsibility	***Persons Responsible***
Overall Project Manager	Muazma Zahid
Engineering Manager	Sadaf Malik
Quality Assurance Manager	Umair Ahsan
End-User Documentation Manager	Capt Zahid Sultan
Requirements Engineer	Umair Ahsan
Software Architecture	Sadaf Malik
Technical Self-Reviews	Muazma Zahid

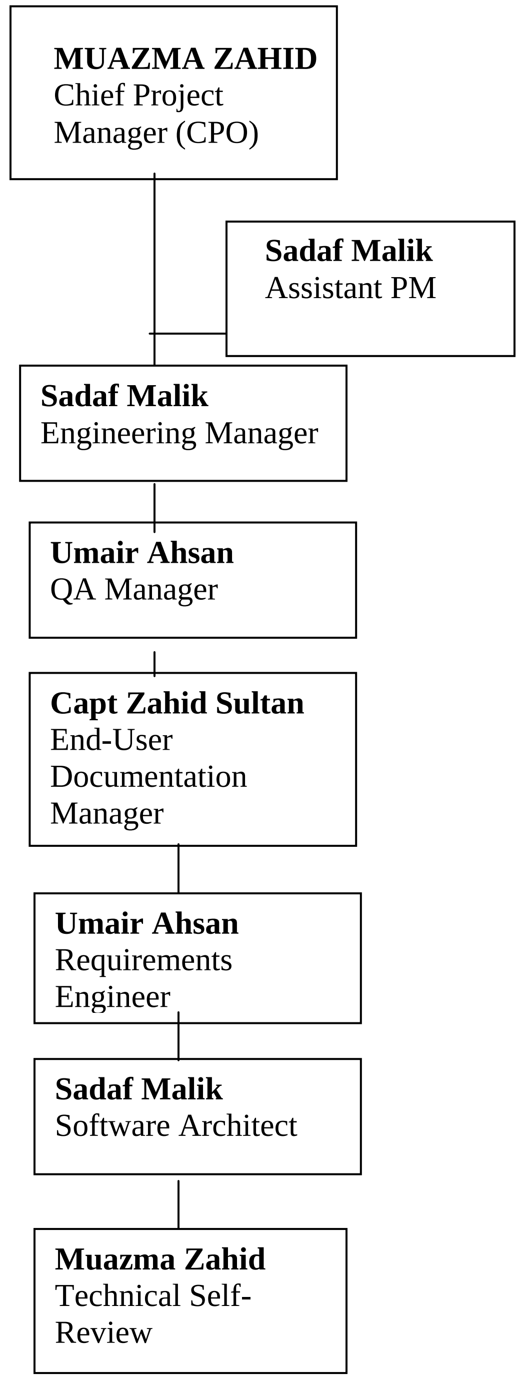


Fig. 3 Organizational Chart for Project Responsibilities

3. Managerial Process

In this section we describe policies that will be adopted to manage VTDS**.** This includes management objectives, priorities, project assumptions, dependencies, constraints, risk management techniques, monitoring and controlling mechanisms, and the staffing plan.

3.1 Management Objectives and Priorities

The main objective is to ensure that time constraints are strictly followed. Also the priority will be given to the quality of work.

During the earlier stages of the project more priority will be given to schedule.

Cost will not be as much a major factor in this project. Though this is a commercial project but it does not fall into the category of high budget projects, so cost management is not the primary goal. Due to work load main concern will be, to meet time constraints and to make sure work is completed on schedule.

More priority will be given to functionality as well. The main aim of the project will be to achieve the maximum possible efficient functions of the project in the minimum possible time. The project team will attempt to strike maximum possible balance between time and functional priority.

Minimum attempts will be made to acquire any third party software. The development team may decide to obtain or modify some existing software for the benefit of the project in an attempt to save time and resources. Existing software algorithms will be employed to provide sufficient tools for efficient and comprehensive development of the software with implementation of new algorithms as well.

3.2 Assumptions, Dependencies and Constraints

It is assumed that the schedule will not clash with the academic schedule of the team members. Also that the team will able to setup the project to test the product.

3.3 Risk Management

This area describes the major risks to the project, which the project plan has been designed to address. It also describes how risks will be tracked and monitored.

3.3.1 Major Risks

The major risks that can impinge on the project are

- Clash of project schedule with other activities of team members
- Work overload.
- Shortage of time
- Availability of hardware
- Lack of software engineering experience and unfamiliarity with tools, biomedical equipment and ECG characteristics.
- Highly Safe Detection is required

3.3.2 Risk Tracking and Monitoring

To avoid work overload the tasks will be distributed among team members in such a way that every personnel is able to give enough time. Every phase will have an informal sub schedule. Main schedule is made flexible enough to accommodate mishaps and undesirable circumstances

It will be made sure before integration phase or during the test plan definition phase that desired hardware and software is acquired. Knowledge to setup the hardware will also be acquired.

Every team member will be given time to get familiar to the tools. Help materials will be acquired for this purpose. Also necessary in time help will be requested from external supervisor.

Any risk factor, suggested by a team member or client will be included in this section for next versions. The possibility of risks emerging during the project is very high so a risk list along with the avoidance mechanism will be kept and updated accordingly.

The possibility of risks emerging after the project is very high as ECG has a lot of safety issues to be addressed which have to be incorporated for an accurate and specific VT detection. In case any risk cannot be overcome the priority will be given to the quality of the product as mentioned earlier that cost is not a factor for this project.

3.4 Progress Monitoring and Controlling Mechanism

3.4.1 Monitoring and Controlling Mechanisms

Project cost, schedule, quality, and functionality will be tracked throughout the project. In a weekly meeting the progress will be reviewed and analyzed by Project Manager and Quality Assurance Manager. Problems encountered by any team member will be discussed and resolved accordingly.

3.4.1.1 Report contents

Separate reports shall be prepared for monitoring the technical, functional, quality and cost monitoring of the project. Progress reports will also be maintained in due course of time. The status reports of the Managing committee will contain the following details:

- Status of the current phase activities
- Estimated time of completion of the current phase
- Milestone deliverables at current phase
- Schedule for the next phase activities
- User Actions

The status reports will be accompanied by Gantt Charts. Various other graphs will also be presented at the managing committee meeting to support the facts laid down in the status reports.

3.4.1.2 Report Format

A standard report format will be developed and circulated to all the members of the project team. All activities will be recorded in a standard manner in these reports. Copies of these reports will be saved electronically. At the same time hard copies of the reports will also be maintained.

3.4.1.3 Reporting structure and frequency

The reporting structure will be developed and circulated to all parties concerned. All reports will be developed on a weekly basis.

3.5 Staffing Plan

The number of personnel is fixed in the current project, considering the different approach of the project at hand. The minimum skill levels are not defined at this stage. The entire duration of the project will be headed and dealt with the same time, each individual acquiring different role during different phases.

There will be no extra personnel acquired during the course of the project besides those that are currently involved in the project.

There will be some necessary training that will be required in the later stages of the project. Necessary arrangements will be made to make available the essential training for the personnel working on the project.

Type of Personnel's	Number of personnel	Required Skill Level / Qualification(s)
Requirement Engineer (s)	2	Experience in Requirements Engineering
Software Designer (s)	2	Software Engineering
Project Manager	1	Software Engineering
Coder (s)	3	Excellent Coding in C++ and MATLAB
QA Manager	1	Experience as QA Officer
Test Officer (s)	2	Experience as Test Officer
Manager (s)	1	Management Skills

4. Technical Process

This section describes the top-level technical processes used on the project including the technical methods, tools, and techniques; major software documents; and supporting activities such as configuration management and quality assurance.

4.1 Methods, Tools and Techniques

4.1.1 Operating Environment

The operating environment will be that of Microsoft Windows. Installation of MATLAB and C++ IDE is mandatory.

4.1.2 Hardware

- ❖ Stand alone IBM PCs.
- ❖ Holter (ECG) Machines

4.1.3 Software tools

- ❖ Compiler or IDE : MATLAB
- ❖ Programming language : C++ and MATLAB
- ❖ Coding standards : IEEE
- ❖ Documentation standards : IEEE

Remarks

Software will have object oriented reusable structure. Documentation will be clear and explanatory. Microsoft Project software will be used to aid in management.

4.2 Software Documentation

The listed documents will be developed for the project, including are milestones, reviews, and signoffs for each document.

Documentation will consist of

- Project Plan
- Requirements Document
- User Interface Plan
- Requirement Analysis

- Specifications
- Testing Plan
- Detailed Design
- Product Review

4.3 Project Support Functions

The project is supported by following other documents. These documents describe the plans for functions that support the software development effort.

- Configuration management Plan and Documentation
- End - user documentation (USER MANUAL)

The plans for these supporting functions will be developed in due time and should be referred to as the need arises. Any other supporting documents that need to be included on the list of the above documents will be added in the later versions of this document.

5. Work Packages, Schedule, and Budget

5.1 Work Packages

The work packages defined for the software development lifecycle are as below. These including the sub-packages and tasks must be completed in order to complete the software.

1. Software Project Initiation
2. Software Concept Development
3. Software Requirements Development
4. Software Architectural Design
5. Software Development
6. Software Implementation and Integration
7. Software Testing and Configuration Management

5.2 Dependencies

5.2.1 Dependencies among work packages

All the work packages discussed above are extensively interdependent. Every package is dependent upon all the packages illustrated before it. And all the tasks within each work-package follow the same schematic.

5.2.2 Dependencies on external events

Various work Products will be dependent on the external approvals etc. Details of these dependencies will be specified in the later versions of this document.

5.3 Resource Requirements

The following resources will be needed.

Hardware Tools:	Stand alone IBM PCs, Holter (ECG) machines.
Software Tools	Programming tools (MATLAB and C++)

Additional resources will be identified in the later versions of this document.

5.4 Budget and Resource Allocation

5.4.1 Budget Allocation

Following is the amount of Budget allocated to the Software processes.

Software Requirements Management	:	15 %
Software Design	:	15 %
Software Construction	:	10 %
Software Implementation	:	7 %
Software Testing and Integration	:	18 %
Documentation	:	10 %
Software Project Management	:	25 %

5.5 Project Schedule

The following schedule will be followed during the development process. The schedule is based on project deliverables. The schedule given below is subject to change as the project development progresses. Pert and Gantt charts also represent this schedule.

PROJECT SCHEDULE FOR VTDS

Based on Project Deliverables, following Chart illustrates the Project Schedule.

Deliverable Name	Due Date
10) Project Definition and List of team Members	15th MAY 2005
11) Project Plan	1st June 2005
12) Requirements Description	15th June 2005
13) Requirement Analysis	1st July 2005
14) Project Specifications	26th August 2005
15) Testing Plan	15th April 2006
16) Detail Design Document	20th April 2006
17) Fully Functional Product Model	15th April 2006
18) Project Report and Review	19th April 2006

Fig. 5-Chart for ATAYOF Project Development Schedule

6. Additional Components

This section defines the additional components needed to manage this project.

- Training plans
- Facilities plans
- Installation plans
- Software Maintenance plans

Details of these areas will be provided in separate documents in due time.

APPENDIX D

TEST PLAN DOCUMENT

Ventricular Tachyarrhythmia Detection System

Test Plan Document

Version (1.0)

Document and Version Control

Document Information

Document Title	Test Plan for VT Detection System
Filename	TestPlan_CIS_v1.0.doc
Creation Date	March 15,2006
Authors	Muazma Zahid, Sadaf Malik, Umair Ahsan, Capt Zahid Sultan
Version	1.0
Distribution List	1. Capt Zahid Sultan PC Saima Nisar
Reviewers	1. Muazma Zahid 2. Umair Ahsan
Passing Review Date	1st April, 2006.

Related Documents

Input Documents	System Requirements Specifications (Annex A-1)
Output Documents	Test Case Document

Document History

S. No.	**Document Version**	**Major Changes**	**Author/s**	**Creation Date**	**Review Date**	**Reviewer/s**
1.	1.0	Initial Draft	Muazma Zahid, Sadaf Malik, Umair Ahsan, Zahid Sultan	March. 15, 2006	April 1, 2006.	Muazma Zahid Umair Ahsan

Project Information

Project Release Information

Project Name	VT Detection System
Project Code	VTDS 06
Project Release Number	1.0
Project Release Date	April 20,2006.
Testing Dates	March 15, 2006 – April 10, 2006
Testing Iteration Number	1.0
Project Modules Information	Software

Project Team Information

Group Leader	Muazma Zahid
Developer Name(s)	1. Sadaf Malik 2. Umair Ahsan 3. Capt Zahid Sultan
Quality Analyst Name	Sadaf Malik
Tester Name(s)	1. Muazma Zahid 2. Sadaf Malik

Remarks

Introduction

Purpose of Document

This document is the master test plan for **VT Detection System**. It serves as an umbrella document to coordinate all test plans for this project. It defines the scope, approach, schedule, risks/mitigations, and entry/exit criteria that are required as part of project planning prior to Execution. It also contains various resources required for the successful completion of this project.

The purpose of this Software Test Plan is to test the functionality and make sure that the requirements stated in the Software Requirement Specification (SRS) are fulfilled.

Product Scope

The VT Detection System is intended to provide an accurate, sensitive and efficient system for VT Detection .The system comprises of software module/s for VT Detection. It invokes a new concept in the field of bio-medical engineering in general and the paradigm of VT detection methods in particular.

Intended Audiences

The document is intended for test personnel to be used as the documented plan for the software/system test activities. Other stakeholders include development Project DS, Group Leader, AFIC(NIHD) doctors and system developers.

Test Objectives

The tests included in this test plan are to be conducted to verify the software implementations for the VT Detection System. Major part of the test work includes software testing for VTDS components:

Test Case Matrix

List of all the test cases is attached.

Test Resources and Environment

The entire test will be conducted either in the college computer labs or in Electrophysiology department of AFIC (NIHD). The environment suitable is with those equipped with Holter Machines and Desktop Computer.

Hardware

The following hardware/system will be used in the testing process:

- Data Acquisition Module (Holter Machines)
- Power Supply Module

Software

The following software /system will be used in the testing process:

- Data Communication
- File /Patient Record Storage
- Abnormality (VT) Identification
- GUI

Testing Tools

All tests for this Phase will be conducted manually. At this time no specialized testing tools are being used. Test cases and bug tracking reports will be generated and documented on Microsoft Word and Excel sheets. Also no automated testing tools will be used.

Recommendations:

Software for bug tracking system is highly recommended for future phases of this project.

Test Personnel

Parties	Contact Person	Role and Responsibilities
DS	Brig Dr. Muhammad Akbar	• Overall Supervision • Work stream Management • Review of Test Plan and Test Cases • Monitor testing schedule and procedure.
Testing Team Lead	Muazma Zahid (muazma@gmail.com)	• QA Team Lead • Development of Test Plan and Test Cases. • Managing and directing testing activity • To Ensure Testing activity comply with project and test plan • Conduct testing
Test Engineer	Sadaf Malik (malik.sadaf@gmail.com)	• Develop test cases and conduct testing • Submit Bug Reports

Testing Schedule

Task	Start Date	End Date	Days
Document Requirement	15-03-06	18-03-06	3
Document Design	19-03-06	19-03-06	1
Setup and familiarity with test environment in the AFIC Labs	20-03-06	22-02-06	3
Create Test Cases	23-03-06	24-03-06	2
Conduct walk-through of Test Plan and Test Cases	25-03-06	25-03-06	1
Test Case Execution	26-03-06	30-03-06	5
Retest incidents and Regression Testing	30-03-06	31-03-06	2
Sign off on Test	01-04-06	01-04-06	1

Risks, Dependencies and Assumptions

Since the development of the VTDS is almost completed and final, so unit and integration testing of the software is not possible. Only the feature testing for Software will be conducted.

The following is a list of risks and contingencies for this testing procedure.

- Testing is contingent to proper and smooth operation of the test environment in the AFIC Labs.
- The source code for VTDS should be available by the start date of testing i.e. 15-03-2006.
- In case of some critical or major bug, time is very limited for consultation with developers. Also there should be some pre-defined procedure to contact with developers for defect management etc.
- The test plan and test schedule are based on the current Requirements Document. Any changes to the requirements could affect the test schedule.

Defect Management (DM) Process

Defects (bugs) found during test execution will be captured and recorded by the testers in a separate database. For now, separate MS Excel sheets will be used. These reports will be shared by Development Manager, Project Manager and all concerned development team members. The following are the steps included in the bug report (a template is attached).

- Title or Summary
- Description of the Problem
- Software release version or phase etc.
- Priority

- Functional area: which software block/module is suspected to have problem
- Traces: attach any trace files/screen shots that are taken as part of the analysis.
- Currently assigned to: e.g. development manager, developer
- Status: Open or closed
- Remarks/comments
- Note: All new additions should be made with a date e.g. new traces, comments/remarks or any additions to description by the tester.

Bug Severity Levels

S. No.	Severity	Definition
1.	Critical	A major part of the system cannot be used, or system / data integrity is in doubt, which causes a halt to the testing. All available resources must be used to resolve the incident, examples are: • Application crashes forcing the tester off the system. • Missing feature. • Output not generated.
2.	Major	Must be fixed before the final sign off the testing phase. Productivity is adversely affected e.g. Error condition is created which was not the expected result of the test, for which there is no recovery for that test, although the user can select other tasks and run other tests.
3.	Medium	Use of the relevant process can continue with a temporary workaround, but a fix must be scheduled before exit. Examples are: • Cosmetic errors. • Problems that do not cause easily noticeable faults.
4.	Minor	Errors that have a little or no impact on interim use or productivity. Fixing these bugs before exit is not mandatory.
5.	Enhancement	Not in specifications, but desirable according to tester.

Debugging Priority Levels

Priority	Definition
Critical	Resolve immediately
Major	Give High Attention
Medium	Normal Queue
Minor	Low Priority

Testing Approach

<u>Entry Criteria</u>

- Sign-off and baseline Requirement and Design specification.
- Completion of this test plan, test matrix and test cases.
- Completion of Unit Testing by Software Developers.
- Complete Installation of hardware/infrastructure configuration at the testing environment site.
- Completion of a Sanity Check of test environment that prove the environment is stable, clean and isolated. The test environment must not have interference of development or production activities during QA period.
- Testers have been committed to testing and completed the sufficient training provided by developers.
- Availability of the system and support person(s) to support the testing environment during testing.

<u>Exit Criteria</u>

- All Critical & High defects have been fixed and a clear strategy has been devised on how to handle any remaining Medium priority defects.

- Completion of all Testing activities according to the planned test cases and conditions.
- All problems/incidents have been resolved, fixed, retested successfully and closed.
- Full record of all problems / incidents and evidence of satisfactory retest maintained.
- All Testing Activities have been stated at Test Report.

Test Execution Procedure

Test Execution steps are follows:

- Ensure the code and the test environment is in place.
- Execute the test cases according to the pre-defined test sequence
  - ➢ Document the actual results
  - ➢ Compare the actual results against the expected results
- Document any discrepancies/bugs in the 'Bug Tracking Document' according to the Incident Tracking Procedures
  - ➢ Assign Bug tracking document to applicable owner. For this purpose an email will be sent to the respective development engineer.
- A brief report showing status for test cases will be issued periodically.
- Errors and incidents will be updated periodically.
- Re-test issues that are turned back for re-test
  - ➢ Regressions tests will be conducted after consulting with development team (if necessary), which may have been affected as a result of the fixes.

Testing Types/Functions Used

Features and flow testing for Software part of **VT Detection System** will be tested. In general following types of testing will be conducted:

- Startup/shutdown Testing
- Feature/function Testing
- Negative Testing
- Unit Testing

- Integration Testing

Testing Types/Functions Not Used

Any other functionality except Software modules will not be tested. In general the following type of testing will not be conducted:

- Installation/Migration Testing
- System level Regression Testing

Test Deliverables

- Test Plan
- Test Cases
- Test Cases summary/status Report
- Bug Report Tracking Documents
- Final Test Summary Report

Test Cases

Module Name: Software

Module Information

Module Name	Software Module
Module Release Number	1.0
Module Release Date	15-03-06
Testing Dates	16-03-06 to 28-03-06
Testing Iteration Number	1
Developer Name(s)	1. Muazma Zahid 2. Sadaf Malik 3. Umair Ahsan 4. Capt Zahid Sultan

Functional Requirements

Module Description	The Software comprises of various modules integrated together.
Functional Requirements	1. ECG Data Acquisition 2. Main Menu 3. ECG Analyzer 4. Record Saving 5. Results Display

Test Case Table

Test Case Name/Title:	**ECG Data Acquisition**
Test Case Number	**FN-REQ-001-VTDS0001**
Purpose	To see if the signal is acquired appropriately from Holter Machines both online and offline.
Precondition	The patient ECG is recorded
Procedure	Computer is attached to Holter Machine.
Expected Result	The input .dat file for the patient ECG recording is added to list for available data
Actual Result	.dat file is seen.
Status	Pass
Bug ID	<In case the test fails, specify a bug id to track it's changes throughout debugging>
Tester	Sadaf Malik
Date	16-03-06
Remarks	<Additional remarks>

Test Case Name/Title: Main Menu	
Test Case Number	**FN-REQ-001-VTDS0002**
Purpose	To see the Main Menu for VT Detection with entire Help for System.
Precondition	Initialize MATLAB and start main_menu

Procedure	Initialize main_menu
	Test all Options
	• Open User Manual
	• Open Options
	    o “What is VT”
	    o “What is ECG”
	    o Wavelet Demo
	• Check Information About
	    o AFIC and NUST(MCS)
	    o Data and Information Flow
	    o Contact Information

Expected Result	All associated files open in their respective formats(.pdf and .pps)
Actual Result	Files opened
Status	Pass
Bug ID	<In case the test fails, specify a bug id to track it’s changes throughout debugging>
Tester	Capt Zahid Sultan
Date	18-03-06
Remarks	<Additional remarks>

Test Case Name/Title: ECG Analyzer	
Test Case Number	**FN-REQ-001-VTDS0003**
Purpose	Perform VT Detection
Precondition	Initialize ECG_analyzer from MATLAB or Click on ECG ANALYZER button in main_menu
Procedure	1. Open ECG_analyzer 2. Choose the data directory (in the left listbox or type directly into the edit window). 3. Choose the result directory (this is either the directory, from where the data is read, or another one, that has to be typed into the edit window). 4. Transfer the data that you want to analyze, from the left listbox into the middle one (by double clicking). Data files can be removed from the middle list box by double clicking. 5. Choose parameters, set checkboxes, choose algorithm, and possibly use standard settings. 6. Press START button. 7. Double click on the result files to view the result and the computed parameters.
Expected Result	Successful execution of all five algorithms o SPEC o WVL0 o WVL1 o WVL2 o WVL3
Status	Pass
Bug ID	<In case the test fails, specify a bug id to track it’s changes

	throughout debugging>
Tester	Muazma Zahid
Date	22-03-06
Remarks	<Additional remarks>
	Noise data results bugs reported to System Developer with tested values.

Test Case Name/Title: Record Saving	
Test Case Number	**FN-REQ-001-VTDS0004**
Purpose	To check if the associated result file is stored properly for further reference.
Precondition	Analyze input .dat file with some algorithm from ECG_analyzer
Procedure	• Press Start form ECG_analyzer window. • Check the associated .dat file for input file and associated header file for example for input file xyz.dat being analyed by five algorithms the respective result files will be: o ExyzjSP.dat and ExyzjSP.hea for SPEC algorithm. o ExyzWVL.dat and ExyzWVL.hea for WVL0 algorithm. o ExyzWVL1.dat and ExyzWVL1.hea for WVL1 algorithm. o ExyzWVL2.dat and ExyzWVL2.hea for WVL2 algorithm. o ExyzWVL3.dat and ExyzWVL3.hea for WVL3 algorithm.
Expected Result	The files are correctly saved on PC in desired result directory.
Actual Result	The files are correctly stored in PC.
Status	Pass
Bug ID	<In case the test fails, specify a bug id to track it's changes throughout debugging>
Tester	Umair Ahsan
Date	23-03-06
Remarks	<Additional remarks>

Test Case Name/Title: Results Display	
Test Case Number	**FN-REQ-001-VTDS0005**
Purpose	To display the result files
Precondition	Double click on the desired result file in .dat format available in result list of ECG_analyzer
Procedure	1. Double click the desired result file. 2. View the parameters result and beat statistics. 3. Compare database results with our own algorithm results
Expected Result	Sensitivity, Specificity, Predictivity and Accuracy must be close to desired values.
Actual Result	Improved Accuracy, Specificity, Sensitivity and Predictivity obtained
Status	Pass
Bug ID	<In case the test fails, specify a bug id to track it's changes throughout debugging>
Tester	Muazma Zahid
Date	25-03-06
Remarks	<Additional remarks>

Test Summary Report

The tests have shown the following results

- All software modules preliminary execution shows desired results
- All modules integration testing illustrate no problem
- Desired results of Algorithms demonstrate improved values of parameters. The mean values of VT Detection System are:

Sensitivity	Specificity	Positive Predictivity	Accuracy
40%-50%	**90.8%**	**72%-86%**	**80%-95% ***

* depending upon noise in data

- Bugs in few noisy data results notified to system developers
- Overall system tests demonstrate 90% accuracy for all components.

Appendix E

Definitions, Acronyms and Abbreviations

- **VT:** Ventricular Tachyarrhythmia
- **VF:** Ventricular Flutter.
- **ECG:** Electro Cardiograph traditionally known as EKG as well.
- **VTDS:** Ventricular Tachyarrhythmia Detection System
- **SPEC:** Spectral Algorithm
- **UML Diagrams:** Various diagrams including Use-Case, Sequence and Data Flow that show the initially perceived outline functionality of the intended system.
- **GUI :** Graphical User Interface
- **UI :** User Interface
- **SRS:** Software Requirements Specification
- **SDP:** Software Development Plan
- **STP:** Software Test Plan
- **PC:** Personal Computer
- **PM:** Project Manager
- **CTO:** Chief Technical Officer
- **CEO:** Chief Executive Officer
- **QA:** Quality Assurance
- **WVL0:** Wavelet 0 Algorithm
- **WVL1:** Wavelet 1 Algorithm
- **WVL2:** Wavelet 2 Algorithm
- **WVL3:** Wavelet 3 Algorithm

Software Project Management Document References

The following documents were referred for scope and detail of SPM Documents.

- IEEE Std 610.12-1990, IEEE Standard Glossary of Software Engineering Terminology
- IEEE Std 730.1-1995, IEEE Guide for Software Quality Assurance Planning
- IEEE Std 828-1998, IEEE Standard for Software Configuration Management Plans
- IEEE Std 982.1-1988, IEEE Standard Dictionary of Measures to produce Reliable Software
- IEEE Std 1012-1998, IEEE Standard for Software Validation and Verification

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