CHAPTER 1

INTRODUCTION

1.1 NEED FOR THE THESIS

Advances in information and communication technology have rapidly enhanced the role of computers in cardiac medicine. Modern computer technology offers immense advantages with respect to capture, storage, analysis and communication of biomedical information. These facilities can be routinely and effectively employed to aid day-to-day diagnosis and management of patients.

Various disciplines have been benefited by the advent of high-performance computing in achieving practical solutions to their problems and the area of health care is no exception to this. Software tools have been developed to enhance the computational capabilities in order to help doctors to prompt diagnosis and treatment. The availability of low-cost high-performance computing technology has encouraged reliable, fast and comprehensive solutions to cardiac disease diagnosis.

The cardiovascular system, comprising of the heart and blood vessels, is one of the most vital systems in the human body. The function of the cardiovascular system is to circulate blood through a network of vessels throughout the body to provide individual cells with oxygen and nutrients and help dispose metabolic wastes. The heart plays a key role in this circulation and any disease afflicting the heart impairs the normal operation of the cardiovascular system.
Heart diseases are the leading cause of death all over the world, claiming over 17.2 million victims annually. With Indians, the risk is four times that of the Westerners and 20 times more than the Japanese. In the modern times, it can be witnessed that there has been an alarming increase in the number of 25-30 year olds succumbing to heart disease. Most people fail to realise that nearly 80 percent of premature deaths which occur due to heart disease can be avoided, if risk factors are under control. These risk factors are stress, unhealthy diet, physical inactivity and smoking.

As early detection can save many lives, cardiac disease diagnosis has therefore gained extraordinary significance. The detection of abnormality must be done not only in time but also with a high degree of accuracy to facilitate therapeutic measures without undue delay.

The following factors have influenced this research work and provided momentum to the development of novel techniques for cardiac disease diagnosis.

**Affordability**: Most people are unable to access quality healthcare because of the high cost. In this scenario, predicting the disease in advance would be ideal. Such a shift, from the days of diagnosis after the onset to the time of predicting the disease well in advance, is imminent. Information technology can play a crucial role in this regard. Early prediction and diagnosis would make treatment less expensive, less complex, and less intense.

**Technical support**: Though many innovative signal processing and analysis techniques have been recently developed, resulting in more powerful clinical indexes, their implementation still remains a difficult task in small sized hospitals due to certain constraints like technical support, cost and ease of use. Hence, there is a need to develop simple, low-cost diagnostic systems to support physicians.
Objective assessment: Human analysis for diagnosis is time consuming and is subject to inconsistent interpretations and assessments. Hence there is ample scope to use information technology to eliminate subjective inaccuracies and provide an objective assessment.

Decision support: The existing diagnostic modalities in the hospital are not fully supportive. Physicians expect more support for faster decision making. Computer based tools can meet these requirements.

Expertise: Lack of expertise can delay diagnosis. Expert systems can provide valuable support to the medical personnel in arriving at quick and reliable diagnosis.

Resources: Small hospitals and rural health centres lack adequate resources to provide quality healthcare to patients. Internet and communication technologies can help establish telecardiology frameworks to cater to the deprived distant and rural patients. Teleconsultation frameworks can help establish communication between experts and between patient and expert for effective diagnosis.

To address these needs, this research work aims at leveraging technology in developing low-cost, high-performance and simple-to-use systems for enhancing the diagnosis of cardiac diseases.

As Albert Einstein puts it: “Computers are incredibly fast, accurate, and stupid; Humans are incredibly slow, inaccurate and brilliant; together they are powerful beyond imagination”.

1.2 HUMAN CARDIOVASCULAR SYSTEM

The heart and circulatory system make up the cardiovascular system. The heart works as a pump that pushes blood to the organs, tissues,
and cells of the body. Blood is carried from the heart to the rest of the body through a complex network of arteries, arterioles, and capillaries. Blood is returned to the heart through venules and veins. Blood delivers oxygen and nutrients to every cell and removes the carbon dioxide and waste products made by those cells. While arteries carry oxygen-rich blood away from the heart, veins carry oxygen-poor blood back to the heart. Twenty major arteries make a path through the tissues, where they branch into smaller vessels called arterioles. These arterioles further branch into capillaries, the true deliverers of oxygen and nutrients to the cells. Most capillaries are thinner than the width of a hair. In fact, most of them are so tiny that only one blood cell can move through them at a time. Once the capillaries deliver oxygen and nutrients and pick up carbon dioxide and other waste, they move the blood back through wider vessels called venules. Venules eventually join to form veins, which deliver the blood back to the heart to pick up oxygen from the lungs. This process of blood flow within the body is called circulation.

1.2.1 Anatomy of the Heart

The heart, a muscular organ which is about the size of a clenched fist, is located in the thoracic (chest) cavity between the sternum (breastbone) and the vertebrae (backbone). A double-layered membrane called the pericardium surrounds the heart like a sac. The outer layer of the pericardium surrounds the roots of the 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. Figure 1.1 shows the basic structure of the heart.
The heart is divided into left and right halves and has four 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 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. Figure 1.2 illustrates the blood circulation within the body.

Figure 1.1 Structure of the heart

Figure 1.2 Simplified human circulatory system
Four valves regulate blood flow through the 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 the lungs to pick up oxygen. The mitral valve lets oxygen-rich blood from the 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, the body's largest artery, from where it is delivered to the rest of the body.

1.2.2 Mechanical Activity of the Heart

A cardiac cycle consists of a sequence of events during one heartbeat. A heartbeat is a two-part pumping action that takes about a second. As blood collects in the upper chambers (the right and left atria), the heart's natural pacemaker (the SA or sinoatrial node) sends out an electrical signal that causes the atria to contract. This contraction pushes blood through the tricuspid and mitral valves into the resting lower chambers (the right and left ventricles). This part of the two-part pumping phase (the longer of the two) is called **diastole**.

The second part of the pumping phase begins when the ventricles are full of blood. The electrical signals from the SA node travel along a pathway of cells to the ventricles, causing them to contract. This is called **systole**. As the tricuspid and mitral valves shut tight to prevent a back flow of blood, the pulmonary and aortic valves are pushed open. While blood is pushed from the right ventricle into the lungs to pick up oxygen, oxygen-rich blood flows from the left ventricle to the heart and other parts of the body.

After blood moves into the pulmonary artery and the aorta, the ventricles relax, and the pulmonary and aortic valves close. The lower pressure in the ventricles causes the tricuspid and mitral valves to open, and
the cycle begins again. This series of contractions is repeated over and over again, increasing during times of exertion and decreasing while at rest. The heart normally beats about 60 to 80 times a minute when at rest, but this can vary. As the body gets older, the resting heart rate rises. Also, it is usually lower in people who are physically fit.

The brain tracks the conditions around - climate, stress, and level of physical activity - and adjusts the cardiovascular system to meet those needs. The human heart is a muscle designed to remain strong and reliable for hundred years or longer. By reducing the risk factors for cardiovascular disease, the heart stays healthy for a longer time.

1.2.3 Electrical Activity of the Heart

The heart is effectively a meshwork of interconnected cardiac muscle cells and electrical stimulation of one cell spreads to neighboring cells. Each of these cells has its own intrinsic contraction rhythm. A region of the human heart called the sinoatrial (SA) node, sometimes called the heart's "natural pacemaker", sets the rate and timing at which all cardiac muscle cells contract. The SA node generates electrical impulses, much like those produced by nerve cells. Since cardiac muscle cells are electrically coupled, impulses from the SA node spread rapidly through the walls of the atria, causing both the atria to contract in unison. The impulses also pass to another region of specialized cardiac muscle tissue, a relay point called the atrioventricular (AV) node, located in the wall between the right atrium and the right ventricle. Here, the impulses are delayed for about 0.1s before spreading to the walls of the ventricle. The delay ensures that the atria empty completely before the ventricles contract. Specialized muscle fibers called Purkinje fibers then conduct the signals to the apex of the heart along and throughout the ventricular walls. The Purkinje fibers form conducting pathways called bundle branches. The impulses generated during the heart
cycle produce electrical currents, which are conducted through body fluids to the skin, where they can be detected by electrodes and recorded as an electrocardiogram (ECG). A typical electrocardiogram is shown in Figure 1.3.

![Electrocardiogram Diagram](image)

**Figure 1.3 Typical Electrocardiogram (ECG)**

1.3 **HEART DISEASES**

Heart diseases refer to the diseases of the heart and the blood vessel system within it. While some are born with heart disease (known as congenital heart disease), others develop during their lifetime. There are more than 50 different types of heart diseases which can be grouped under problems in the:

- Heart chambers
- Heart muscle
- Heart valves
- Coronary arteries and coronary veins
- Electrical system
- Heart lining
Some common heart diseases are briefed below:

- The types of heart disease that affect the heart chambers include:
  - Congestive heart failure
  - Cor pulmonale

  Congestive Heart Failure (CHF) is a condition that results from any structural or functional disorder of the heart which impairs the ability of the heart to fill or pump a sufficient amount of blood throughout the body leading to body’s failure. Cor pulmonale, also known as pulmonary heart disease, is an enlarged right ventricle.

- The types of heart disease that affect the heart muscle include:
  - Cardiomyopathy
  - Myocarditis

  Cardiomyopathy means heart muscle disease which is the deterioration of the function of the heart muscle leading to arrhythmia (irregular heart beat) or sudden cardiac death. Myocarditis or Inflammatory heart disease is the inflammation of the heart muscle and/or the tissue surrounding it.

- The types of heart diseases that affect the heart valves, called valvular heart diseases include:
  - Mitral stenosis
  - Mitral valve regurgitation
  - Mitral valve prolapse
  - Aortic stenosis
- Aortic regurgitation
- Tricuspid stenosis
- Tricuspid regurgitation
- Rheumatic heart disease, a condition in which the heart valves are damaged from rheumatic fever.

These valvular heart diseases are diseases caused due to defect in one or more valves of the heart.

- Heart disease types that affect the coronary arteries and veins include:
  - Angina pectoris, or just angina
  - Heart attack, also known as a myocardial infarction or MI
  - Coronary artery disease (CAD), also known as ischemic heart disease (IHD) or coronary heart disease (CHD)

Coronary artery disease is a disease caused by the accumulation of plaques within the walls of the coronary arteries interrupting the blood supply to the heart muscle (myocardium). Chest pain (angina) and heart attack (myocardial infarction) are the major symptoms of this disease. Ischemic heart disease (IHD) is a disease characterized by reduced blood supply to the heart muscle, usually due to blockage of the coronary arteries.

- Arrhythmias are those types of heart diseases that affect the electrical system. They can cause the heart to either beat too fast (tachycardia) or too slow (bradycardia), or irregularly. These kinds of heart disease include:
  - Sinus tachycardia
  - Sinus bradycardia
- Atrial fibrillation
- Bundle branch block
- Premature atrial contractions
- Ventricular tachycardia
- Ventricular fibrillation

Cells that line the inside of the heart muscle and valves are known as the endocardium. The outside of the heart is surrounded by a thin sac known as the pericardium. Types of heart disease that can affect the heart lining, either the endocardium or pericardium include:

- Endocarditis, which is an inflammation of the endocardium. The heart valves are most commonly affected by this type of heart disease.
- Pericarditis (inflammation of the pericardium)

Congenital heart diseases are those diseases that people are born with. These diseases can affect any part of the heart, including the heart muscle, valves, or blood vessels. The major types of congenital heart disease include:

- Ventricular septal defect (VSD)
- Atrial septal defect (ASD)
- Pulmonic stenosis
- Congenital aortic stenosis

Cardiovascular diseases is a broader term used to include both the heart diseases and the diseases that involve the blood vessels (arteries and veins) leading to and from the heart. Research suggests that women generally suffer from diseases affecting the blood vessels while men usually suffer from those affecting the heart muscle.
1.4 HEART DISEASE DIAGNOSIS

In this section, the common diagnostic tools used for heart disease diagnosis are presented.

An electrocardiogram (ECG), the recording of the electrical activity of the heart, is used to identify arrhythmias, ischemic heart disease, right and left ventricular hypertrophy and presence of conduction delay or abnormalities (eg. Left bundle branch block). An ECG may also diagnose acute myocardial ischemia if ST segment depression or elevation is present.

An echocardiogram is a test in which ultrasound is used to examine the heart. It is an invaluable tool in providing the doctor with important information about the size of the heart chambers, pumping function, valve function, blood volume status, fluid in the pericardium, congenital heart diseases, blood clots or tumours within the heart and infection of the heart valves.

Cardiac stress test helps to diagnose patients with CAD or IHD. Patients with coronary artery blockages may have minimal symptoms or normal ECG at rest. Alternatively, patients with no heart disease may have fairly convincing symptoms and a suspicious ECG. Both groups may benefit from a cardiac stress test during which exercise on a treadmill is used to stress the heart and expose hidden disease or to help rule it out. During exercise, shortness of breath, chest discomfort and dizziness may suggest underlying heart disease. A drop in blood pressure during exercise may indicate heart disease. ECG monitored during exercise is compared with ECG taken during rest. Changes in the ST segment and T waves may indicate heart disease. Exercise may provoke arrhythmias which may not be seen at rest.
A Holter monitoring process is a continuous tape recording of a patient’s ECG for 24 hours. This continuous 24 hour long monitoring is much more likely to detect an abnormal heart rhythm, when compared to the ECG which lasts less than a minute. It can also help evaluate the patient’s ECG during episodes of chest pain, during which changes suggesting ischemia may occur.

Cardiac catheterization is a specialized study of the blockages in the coronary arteries during which a catheter, or thin hollow flexible tube, is inserted into the artery of the groin or arm. Under x-ray visualisation, the tip of the catheter is guided to the heart. Coronary angios (an x-ray angiogram movie) of the heart and blood vessels are obtained while injecting an iodinated colourless dye or contrast material through the catheter into the opening or mouth of a coronary artery. The iodinated solution blocks the passage of x-rays. X-ray movie pictures taken during the injection of the contrast material allow the coronary arteries to be visualized. The coronary arteries are vital because they supply oxygen and nutrients to the heart muscle. Without blood flow, the muscle would sustain permanent damage in the form of a heart attack or myocardial infarction.

Computed Tomography (CT) and Magnetic Resonance Imaging (MRI) angiograms are non invasive angiograms as against catheter angiograms. The advantage is that the physician does not need to insert a catheter directly into vein or artery to inject the dye. The physician administers a contrast agent into a peripheral vein (usually in the arm) using a needle. This contrast agent highlights blood flow and allows the physician to visualize blocks in arteries on a CT or MRI scan.
1.5 SCOPE OF THE RESEARCH WORK

The functioning of the cardiac system and the major diseases associated with the heart have been discussed in the previous section. It is a vast area for research and hence, focus has been restricted to the following sub areas, with an objective of supporting the physicians in their diagnosis and ensuring better healthcare. Accordingly, the scope of the research work encompasses:

1. Development of diagnostic systems for the classification of
   (i) Cardiac Arrhythmia based on ECG signal using Wavelet Transform
   (ii) Cardiac diseases based on heart rate variability using linear and nonlinear measures
   (iii) Heart murmurs using wavelets and neural networks
2. Design and development of a novel rule-based ECG analyser
3. Design and development of rule-based expert systems for
   (i) Diagnosis of chest pain
   (ii) ECG analysis
   (iii) Diagnosis of Ischemic Heart Disease
4. Proposal of low-cost, easy to implement frameworks for
   (i) Telecardiology for rural healthcare
   (ii) Teleconsultation for medical diagnosis

1.6 OUTLINE OF THE THESIS

This chapter presented the need for simple, reliable, affordable and fast techniques for enhancing heart disease diagnosis, the anatomy of the heart, the mechanical and electrical activity of the heart, different types of heart diseases and the modalities used for their diagnosis. The development of
two classifiers for arrhythmia classification based on ECG signal using Wavelet Transform is discussed in Chapter 2.

Heart rate and heart rate variability (HRV) are important measures that reflect the state of the cardiovascular system. Classification of cardiac diseases based on heart rate variability using linear and nonlinear measures is presented in Chapter 3.

Heart auscultation is a non invasive diagnostic tool used for the detection and classification of heart disorders. Classification of heart murmurs using wavelet decomposition and neural networks is discussed in Chapter 4.

Automated electrocardiogram (ECG) analysis can aid the physician in speedy diagnosis of cardiac diseases. Chapter 5 presents the design and development of a rule-based ECG analyser based on lead measurements from the 12 ECG leads.

Expert systems aid physicians in arriving at reliable and faster diagnosis. Design and development of rule-based expert systems for a) chest pain diagnosis b) ECG analysis and c) Ischemic Heart Disease diagnosis is dealt with in Chapter 6.

Telecardiology aims to provide healthcare to cardiac patients living in remote areas. Teleconsultation systems provide tools for establishing meaningful communication between physicians and patients for diagnostic purposes. These technologies assist doctors in providing quality and timely health care to society. Chapters 7 and 8 discuss the design and development of cost effective, easy-to-implement frameworks proposed for telecardiology and teleconsultation, respectively.

Chapter 9 summarizes the contributions in this research work and provides suggestions for future work in the field of diagnosis of heart diseases.