Automatic Segmentation of Mitral Valve for Detection of Rheumatic Heart Disease using Ultra Sound Images

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Declaration

I certify that this research work titled "*Automatic Segmentation of Mitral Valve for Detection of Rheumatic Heart Disease using Ultra Sound Images"* is my own work. The work has not been presented elsewhere for assessment. The material that has been used from other sources it has been properly acknowledged / referred.

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Language Correctness Certificate

This thesis has been read by an English expert and is free of typing, syntax, semantic, grammatical and spelling mistakes. Thesis is also according to the format given by the university.

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Copyright Statement

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Abstract

Rheumatic Heart disease is an outcome of continuous episodes of rheumatic fever. It directly damages heart valve especially mitral valve, which leads to thickened leaflet and fused tips. So results in mitral stenosis a condition with narrowed valve opening which results in reduction of flow of blood. Echo-cardiogram provides valuable information about heart condition for exact and timely detection of heart disease but segmentation of ultrasound images has been considered as a perplexing task due to its intensity combination or low contrast. Manual segmentation is a complex process depends mainly upon the intensity of the images but often it includes local information too. It also requires highly trained team of doctors, radiologists and technicians. The proposed method incorporate automatically initialization of active contour with distance regularized level set segmentation algorithm in order to segment the region of interest. Our approach combines the advantages of level sets that uses the prior knowledge like shape, intensity, contours and edges of object to be segmented. The aim of the task is to segment anterior mitral valve (AML). The results of segmentation is demonstrated quantitatively with automatic curvature calculation, spline modelling, and Skeletoniztion and Dice similarity coefficient (DSC) matrices. Results are compared with the ground truth provided by highly trained manual segmented dataset. Data set used in this task is provided by the Real Hospital Portuguese, in Recife, Brazil. The results are verified using WHF criteria. The accuracy came out to be 82%. Proposed methodology also compared with Piers method.

Keywords:

Distance regularized level set, dice similarity coefficient, echo-cardiogram, segmentation, anterior mitral valve

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Chapter 1: Introduction

1.1 Introduction

Cardiovascular disease (CVD) known as heart diseases are class of disorders that involves the blood vessels of heart. CVD is a broad class of heart disease which include coronary heart problem which is reduction of blood flow in heart muscle due to plague in the heart arteries .CVD also includes stable angina, unstable angina sudden cardiac death. It also includes Rheumatic heart disease, stroke, vascular heart diseases, heart valves problem. Heart diseases are of different types common types include: electrical, structural or mechanical and circulatory [1]. Irregular or abnormal heart beats are taken under the class of arrhythmia are due to electrical activity of the heart. It might include an extra heart beat or sometimes it missed a heartbeat which results in fast or slow heartbeat [2]. Circulatory diseases of heart are results of circulatory systems such as high BP, high cholesterol results in blockage of heart vessels. Third type is structural heart disease which include deforming of heart muscles, valves and veins one such disease is Rheumatic Heart disease. In which heart's mitral valve directly affected by the untreated strep throat.

There are many factors that can cause CVD such as elevated blood pressure , CVD includes high blood pressure, unhealthy and poor diet, drinking alcohol, diabetes , high cholesterol level, delayed exercise , poor life style, genetics, age, drugs, stress any many more. Genetic factor that can transfer in men in average age of 55 and in women it's about 65 age. The risks of stroke doubles after age of 55. CVD is noticeable in older age is due to high serum cholesterol level which affects heart's working.

According to studies about 90% of CVD are avoidable. The risk of CVD can also be eliminated completely or partially with minimizing many risk factors like life style, hygiene condition, cutting down alcohol consumption. Regular exercise, organic food, proper and healthy diet, reduction of salts and fats, timely and proper medications. However there are risk factors which are unavoidable such as age, gender and genetics.

World health organization (WHO) has declared for most cause of death worldwide. Common type of CVD is coronary heart disease. The CVD have been caused more deaths annually than more other reasons. Number of people died due to CVD is about 17.5 million in the whole world that is about 31-32 percent of entire deaths [4]. This percentage is increases day by day. 75 percent of these deaths are caused in under developing areas have limited access to required health facilities. Due to lack of awareness and lack of services CVD are not detected in early stages so the risk of death even increases in this case. Figure down below shows the top causes of deaths and their percentages. Among these deaths 31.5% are due CVD, 13% are caused by high BP, 6% by smoking and 6% by alcohol consumption. In United States of America every 1 out of 7 person died due to heart disease which is about 375000 deaths every year [5]. Males have been reported more than females to get CVD.

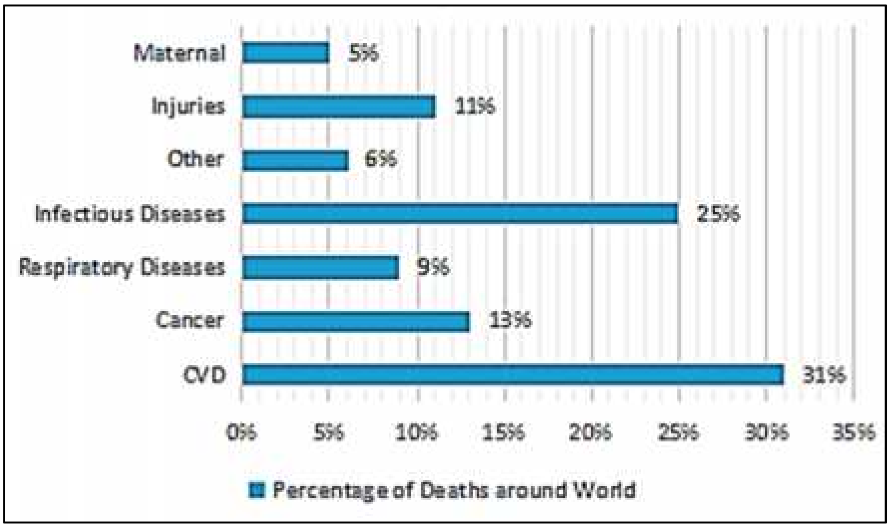


Figure 1.1 Top Causes of Deaths Worldwide [7]

In Pakistan CVD has declared one of the deadly disease along with 20 other diseases. Data collected from health organizations shows 9.87% of deaths are result of CVD. Major causes of CVD in Pakistan is hypertension, body mass index (BMI), dyslipidemia

The symptoms of CVD are not so noticeable in early stages until it runs in the family. But due to unawareness and less knowledge about this disease the primary sign is heart stroke or heart attack. It may include chest pains, severe pain in the left arm, and difficulty in breathing. It also includes difficulty in speaking, vision, loss of consciousness, dizziness, and loss of balance, headache, and responsiveness of one side of body.

Rheumatism or Rheumatic Heart disease a type of structural disease of heart. In which heart Mitral valve damages due to untreated long episodes of rheumatic fever. Whereas rheumatic fever is caused due to strep throat. It is a viral disease caused by special type of bacteria of class A. This can results in permanent damage to heart valve. The damage is not limited to heart it also affects connective tissues, joints skin or brain. It is not a short term disease it might take a long time to develop but results could be dangerous like heart attack.

Although RHD can be found in any age but it is common in children who get repeated episodes of strep throat infection. It is common disease in under developing countries due lack of facilities and services.

Common indications of rheumatic fever could vary person to person. Some of common indications for rheumatic fever are: fever, swollen, tender painful joints (knee and ankle joints are more noticeable), sudden indication of lumps under the skin, redness appearance or rashes on chest, back and abdomen, shortness breath, in- controllable movement of muscles like arms, legs , facial muscles, chest discomfort, weakness. These physical changes can lead towards the idea of having rheumatic fever and RHD. It is not compulsory to have these noticeable changes in everybody. It may vary according to heart valve damage.

Initial diagnosis of RHD is to check for strep first. If a person is well aware of his surroundings or family history of RHD may check for strep infection. This initial test include throat culture and blood test.

Routine physical exams might results in murmur. The blood leakage around heart valves causes murmur to happen. Rub is another type caused when inflamed tissue rub with each other. These are primary tests for strep or rheumatic fever. While other test for RHD includes: Echo cardiogram (ECG), ECHO, chest X-Ray, cardiac MRI. ECG is a record of strength and timing of heart's electrical activity. ECHO is a sound wave test of heart used for detection of abnormality in heart chambers. It a pictorial representation of sound of heart in the form of ultrasound. ECHO is very useful test for detection for RHD as it provides a huge information about the size, position and damage to valves.

1.2 Motivation

Cardiovascular diseases are leading cause of death globally. The cardiovascular diseases have caused almost 17.5 million deaths per year in the universe that is total 32% of entire death chart. Rate of deaths are increasing with each day in the developing countries. Pakistan is also considered as developing country similarly 31 to 45% of deaths are due to heart issues. About 200,000 people die due to CHD per year which is 410/100,000 of the population. RHD is one of the main leading cause of premature deaths and disabilities in Pakistan. Previously surveys have done and results are shocking average age is 25 to 28 facing RHD according to World Health organization. Heart sound imaging is one of the techniques to get information about heart structure and state of art, but it requires highly trained technicians to look for exact location of heart Mitral valve and its movement.

1.3 Problem Statement

Pakistan is a developing country facing the issues of heart diseases as one of the leading causes of deaths each year. It is important to diagnose the underlying problem behind the main stream disease called heart failure. The motivation of this research work is to develop an automatic system to segment the heart's mitral valve using ultrasound videos for detection of rheumatism. Manual segmentation is a time taking long process requires extra care and human power while automatic segmentation is more robust. It can help in differentiate between healthy and unhealthy valve condition for early detection of RHD and helps to save precious lives by easy and on time diagnosis.

1.4 Scope

The highest percentage of diseases are due to heart and circulatory disorders. Due to this research, it will become possible to detect irregularity in Mitral valve's physical parameters and thus patients can be sent to doctors on time and lives could be saved by proper treatment on time providing early detection of heart attacks. It can be very helpful in remote aboriginal communities (small and far away communities) and developing countries like Pakistan especially in the rural area where lack cardiologists and equipment required for the diagnosis of heart diseases is. This research helps in designing a system which can be part of telemedicine and help improve the health facilities in the backward areas of Pakistan.

1.5 Objectives

Heart valve analysis is emerging field in biomedical image processing. It can be very helpful in early diagnosis of irregular heart activity which assists cardiologist in effective and on time diagnosis of RHD. This research assists in developing a reliable and automated system for the early diagnosis of RHD especially in under developed areas. Main outcomes of this research are:

1. To formulate algorithm for identification of location of mitral valve in ultrasound images using image processing techniques.
2. To develop method for classification for heart Mitral valve on the basis of machine learning algorithm.

The aim of the proposed research is to provide aid to the doctors in the diagnostics process especially in the rural area where there is lack of cardiologist and healthcare facilities and not to evade doctor's role.

1.6 Thesis Structure

The rest of thesis is structured as follows

Chapter 2 explains the clinical background in detail. It presents circulatory system, structure and system of heart, Cardiac cycle, Mitral valve structure, Mitral valve pathologies and Echocardiography.

Chapter 3 presents the detailed systematic review of the present state of art techniques used for Mitral valve segmentation and research already done in this area. It discusses different types of method used for calculation of physiological parameters.

Chapter 4 explains the complete methodology adopted to solve the problem highlighted in the problem statement and to achieve the objectives stated above in section 1.3 & 1.5 respectively. It presents the complete flow of the proposed methodology and detailed explanation of algorithm according to each phase i.e. DICOM files preprocessing, initial seed feeding, segmentation of Mitral valve and classification of segmentation into normal and pathological cases.

Chapter 5 presents the detailed results and performance evaluation of proposed methodology. The performance parameters used for evaluation of phases is explained and there results are shown with help of figures, graphs and tables.

Chapter 6 states the summary of the thesis and the future work that can be done in order to extend this research further.

Chapter 2: Clinical Background

This chapter explains clinical background and medical terms regarding structure of heart in order to understand Rheumatic Heart Disease and Mitral valve pathologies in a board way.

2.1 Circulatory System

The organ system that permits blood circulation and provides essential nutrients (such as amino acid and electrolytes), oxygen, carbon dioxide, hormones and blood cells to and from the cells of body is called circulatory system. It is an enormous system with combination of organs and vessels. It maintains temperature by blood circulation and pH through bicarbonate ions acting as buffer solutions. Circulatory system further divided into two main systems that is lymphatic system and cardiovascular system. Both of these systems are independent but work together for proper function of human body.

Lymph is a colorless fluid essentially recycled excess blood plasma after it has been filtered from the interstitial fluid, system responsible for circulation of lymph in the body is lymphatic system. Passage of lymph is larger than a blood path. Lymphatic system is composed of lymph, lymph vessels, lymph nodes and lymph tissues. Conduction of lymph is done by lymphatic vessels. Its other main function is adaptive immune function. It is not a close system.

Cardiovascular system is responsible for blood circulation in the body. It comprises of important components like heart, blood vessels and blood. Blood consists of red blood cells, plasma, white blood cells and platelets. Dedicated network of veins and arteries are pathways for the blood flow through heart. In adults there is about 4 to 7 liters of blood which almost 7 percent of entire body weight. Cardiovascular system is responsible for maintaining blood pressure in the body.

Circulations are of two types:

- Systemic circulation
- Pulmonary circulation

Pulmonary circuit provides the blood flow between heart and lungs for sake of oxygenation. The systemic circuit provides oxygenated blood flow between heart and rest of body. Usually arteries carry oxygenated blood and veins carry de oxygenated blood but pulmonary circulation is exception to this rule. Pulmonary circuits transport de oxygenated blood from heart to lungs via pulmonary arteries where as it transport oxygenated blood from lungs to heart via pulmonary veins. Systemic circuit consists of vast network of arteries, veins and blood vessels for the transport of oxygen rich blood. Cardiovascular system is a huge system but most vulnerable to diseases. It is a close form system so blood cannot leave the network of blood vessels.

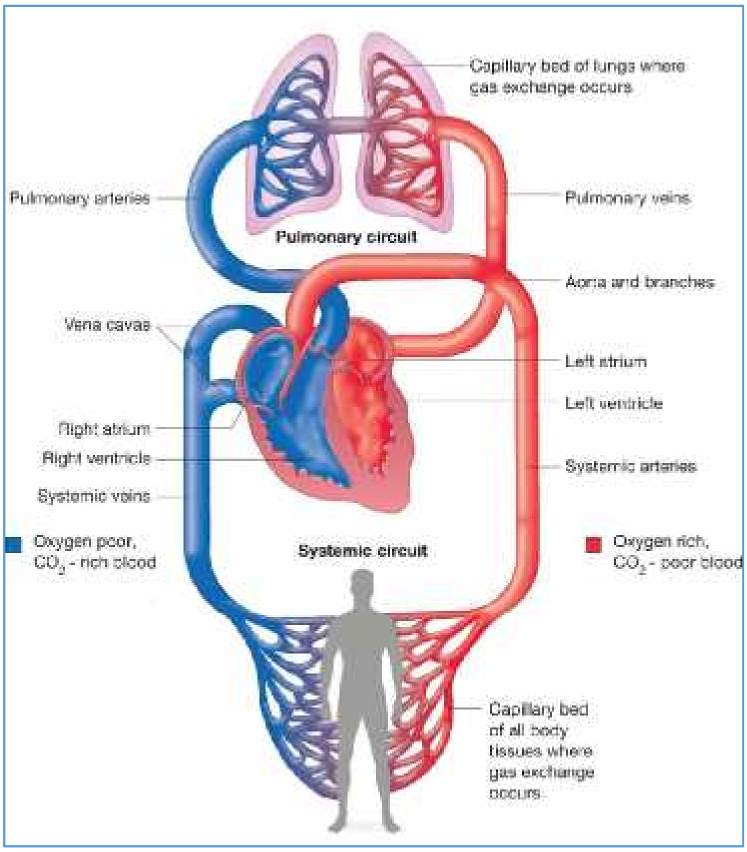


Figure 2.1: Circulatory system with Pulmonary and Systemic Circulation [6]

2.2 Heart

Heart is central part of cardiovascular system. It is responsible of blood pumping in the body. It is a muscular organ located in the middle of chest, between lungs within thoracic cavity. Its size is about a large fist. It weighs about 250 to 350 gm. Heart act as pump as it pumps blood through three divisions: the coronary, the pulmonary and the systemic. The coronary circulation is basically central to the heart takes blood directly from main artery coming from the heart. Whereas systemic provides blood flow between heart and lungs and last pulmonary is responsible for blood flow within rest of body. Heart is divided into four chambers on the whole two pumps: a left pump consists of left atrium and left ventricle and right pump consists of right atrium and right ventricle. It is compulsory for blood to travel in both pulmonary and coronary circulation as the structure of heart is not symmetrical. The atria are the chamber that receives blood whereas ventricle pumps blood. The de oxygenated blood comes into right atrium from veins and goes to lungs through right ventricle for the purpose of oxygenation and removal of carbon di oxide. Then oxygenated blood is pumped to left atria and then passed to left ventricle, from here blood is pumped to different organs through aorta. These four chambers are separated by the valves. The atrioventricular valves are between atria and ventricle. There is tricuspid valve lie between right atrium and ventricle whereas bicuspid valve which is also known as Mitral valve lies between left ventricle and left atrium. Once blood is pumped out of the left ventricle and into the aorta, the aortic valve closes preventing blood flowing back into the left ventricle.

Heart is made up of muscular layers. It is a three layer organ that are:

1: the epicardium

2: the myocardium

3: the endocardium

The epicardium is the outer layer of heart. The myocardium consists of heart muscle it made middle layer and bulk of heart wall. While inner layer is endocardium.

2.3 Cardiac Cycle

The cardiac cycle comprises a complete relaxation and contraction of both the atria and ventricles. It is a complete heart beat which consists of electrical and mechanical events and repeat itself with every heartbeat. It last for approximately for 0.8 seconds. Whereas blood is circulated with systemic and pulmonary circuit with heart beats. The atria and ventricles coordinate with each other for effective blood flow.

The cardiac cycle consists of two phases:

1: Systole: the contraction phase

2: Diastole: the relaxation phase

Human heart beats over 100,000 times per day.

2.3.1 Systole

Systole is period of contraction of ventricular of the heart that occurs between first and seconds sounds of the heart. It is a process of ejection of blood into the aorta and pulmonary trunk last. It last for 0.3 to 0.4 seconds. During systole blood is pumped out of the heart into aorta and pulmonary artery through opening of aortic and pulmonary valves during this time period atrioventricular valve is closed to ovoid back flow of blood.

2.3.2 Diastole

Diastole is part of cardiac cycle in which heart is refilled with blood. It occurs when heart muscles relaxes. In this stage human blood pressure decreases. Blood run through the mitral and tricuspid valves. Right atrium receives blood from the body whereas left atrium receives blood from the lungs after oxygenation. Left and right atria contracts at the end of diastole period pushing extra blood into ventricles.

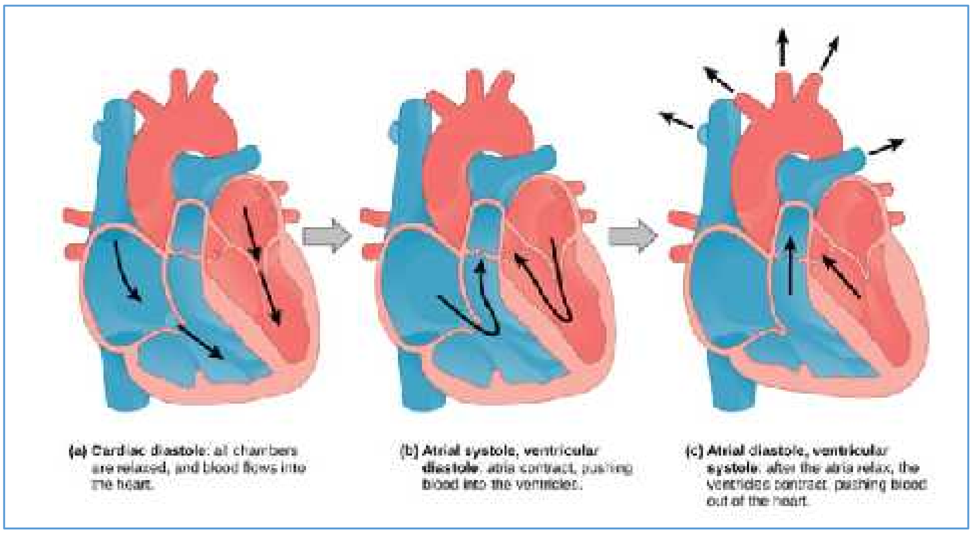


Figure 2.3: Systole and Diastole Complete Cycle [11]

2.4 Mitral valve

The mitral valve also known as bicuspid valve. It is located in the left side of heart between left atrium and left ventricle. Atrioventricular valve consists of mitral valve and tricuspid valve. Blood flows through mitral valve in open state with diastole contraction. While it is remain closed for left ventricle contraction or systole period in order to prevent backward flow of blood. Unlike tricuspid valve which is separated by muscle by its counterpart (the pulmonary valve), the mitral valve is adjacent to the aortic valve.

The normal function of mitral valve consists of six components:

i. The left atrial wall
ii. The annulus
iii. The leaflets
iv. The chordae tendineae
v. The papillary muscles
vi. The left ventricular wall

Typically size of mitral valve varies from 0.62 to 0.93 square inches in area. As name indicates it has two leaflets or cusps that are: anterior mitral leaflet (AML) and posterior mitral leaflet (PML). The AML covers about two third of the valve whereas PML has a large surface area.

During left ventricle diastole, after the pressure drops in the left ventricle due to relaxation of ventricular myocardium mitral valve opens and allows blood transport from left atrium to left ventricle. During the early filling phase of left ventricle about 70 to 80 percent of blood flows across the mitral valve.

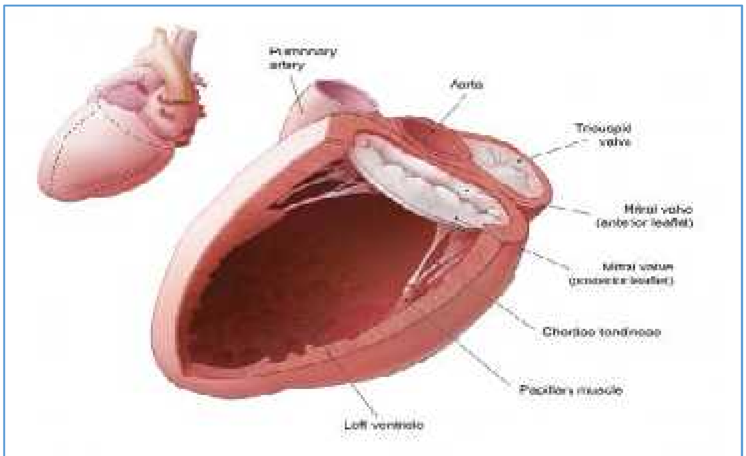


Figure 2.4: Components of Mitral Valve [5]

2.5 Heart valve Pathologies

There are four heart valves: mitral valve, aortic valve, tricuspid and pulmonary valve. Any defect or damage to any one of them can lead to serious heart diseases. The mitral and aortic valves are the ones most frequently affected by heart diseases.

Normally heart valve are unidirectional and ensures the blood flows with proper force in the proper direction on proper time. In pathological cases heart valves suffers from following malfunctions:

1: Stenosis

2: Regurgitation

3: Atresia

2.5.1 Stenosis

In valve stenosis the valve slaps become thick and hard and they may fuse together. Which results is narrowed opening and results in reduction of blood flows through the valve. A stenotic valve forces blood to back up in the adjacent heart chamber. As a result of poor pumping action heart muscle enlarges and losses its elasticity and efficiency. The blood pooling in the chambers have tendency to clot and increase the risk of strokes.

In mitral stenosis, blood flow is reduced through the narrowed valve opening, so the volume and pressure of blood in the left atrium increases. Rheumatic heart disease is also result of mitral stenosis.

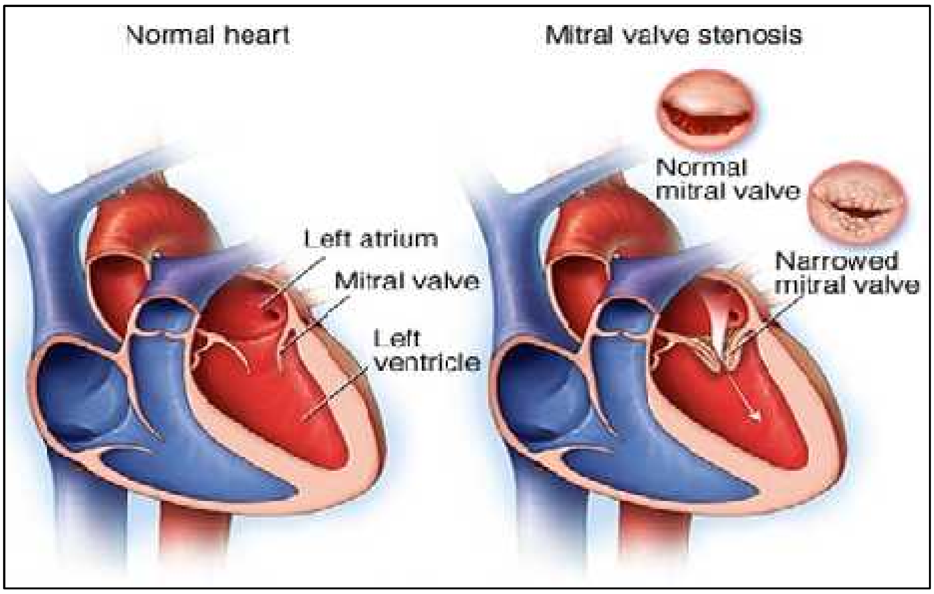


Figure 2.5.1: Normal Heart verses Mitral Stenosis [4]

2.5.2 Regurgitation

Regurgitation is a condition of prolapse commonly occurs due valve flaps bulging back. Due to this valve do not close properly and can lead backward blood flow. This poor pumping of blood places a strain on heart. It can cause heart to work harder and may not pump required amount of blood.

Regurgitation occurs when:

i. Blood flows back to the valve as the leaflets are closing
ii. Blood leaves through the leaflets when they should be completely closed

There are four types of regurgitations occurs

- Mitral regurgitation
- Aortic regurgitation
- Pulmonary regurgitation
- Tricuspid regurgitation

Mitral regurgitation is leakage of blood backward through the mitral valve into left atrium each time when the left ventricle contracts.

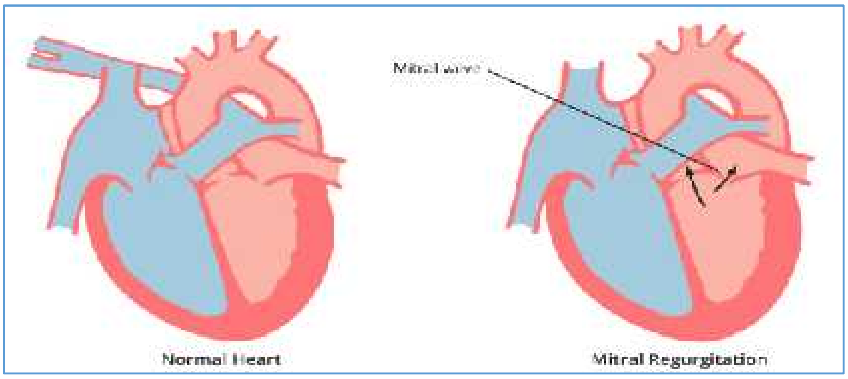


Figure 2.5.2: Normal Heart verses Mitral Valve Regurgitation [9]

2.5.3 Atresia

There is no valve formed in this situation and solid sheet of tissues blocks blood flows between heart chambers.

2.6 Echocardiography

Echocardiography is a test that uses sound waves to produce a live image of heart. The image is called echo cardiogram. It allows doctor to monitor how the heart is working and valves are functioning.

It is a noninvasive test which make it painless. It depends on the need of information what type of echo is required. Each type of Echocardiography involves non to few risks.

It is used for different need like:

Finding clots in heart

Finding fluids in sac around the heart

Finding problems with heart valves

Finding heart problems even before birth is fetal echo-cardiogram

2.6.1 Types of echo-cardiogram

There are several types of echo-cardiogram:

- Transthoracic echo-cardiogram
- Transesophageal echo-cardiogram
- Doppler echo-cardiogram
- Stress echo-cardiogram

There is very little risk in noninvasive echo-cardiograms such as Transthoracic, stress and Doppler test. Person may feel a little discomfort as the transducer or scanning instrument is placed against the chest with a slight force. It is important to apply a little pressure in order to get a clear image of required part.

In stress and Doppler test one may feel a little dizziness due to a short time irregular heartbeat.

Transesophageal is a type of invasive echo, in which a tube is passed to the throat to get a clear image of heart. One might feel discomfort for some hours.

Results of echo-cardiogram may results in:

- Change of heart size
- Damage to the heart muscles

- Valve problems
- Heart problems
- Pumping strength

Highly trained technicians are required to conduct this test.

There are different format to collect results such as: mp4, mp3, DICOM. Not everyone can understand the visual representation of heart. Doctors and radiologist after screening ultrasounds deduce the problem.

Chapter 3: Literature Review

Medical imaging processing is not a new field of research but it has always a room for new and interesting work. It plays a vital role in automated diagnosis of different diseases. The technique of ultrasound imaging have its own advantages like it is a real time or live process, it is transferable, noninvasive tool for the radiologists in assessing the internal organs of a human. When ultrasound is used to image a heart it is called Echo-cardiogram and this technique summarizes under the term Echocardiography. It provides a detailed structure of heart with chamber size, valves information, and heart functions well as the sac around the heart (pericardium).

The leading cause of death worldwide is cardiovascular diseases and one of the best method to increase the survival rate is based on early diagnosis using image processing techniques. Rheumatic fever in repeated episodes is main cause of mitral stenosis which is in acute state cause rheumatic heart disease. It is important to get all information regarding position, size and shape of valve for only detection of RHD but also to find cure for it on time.

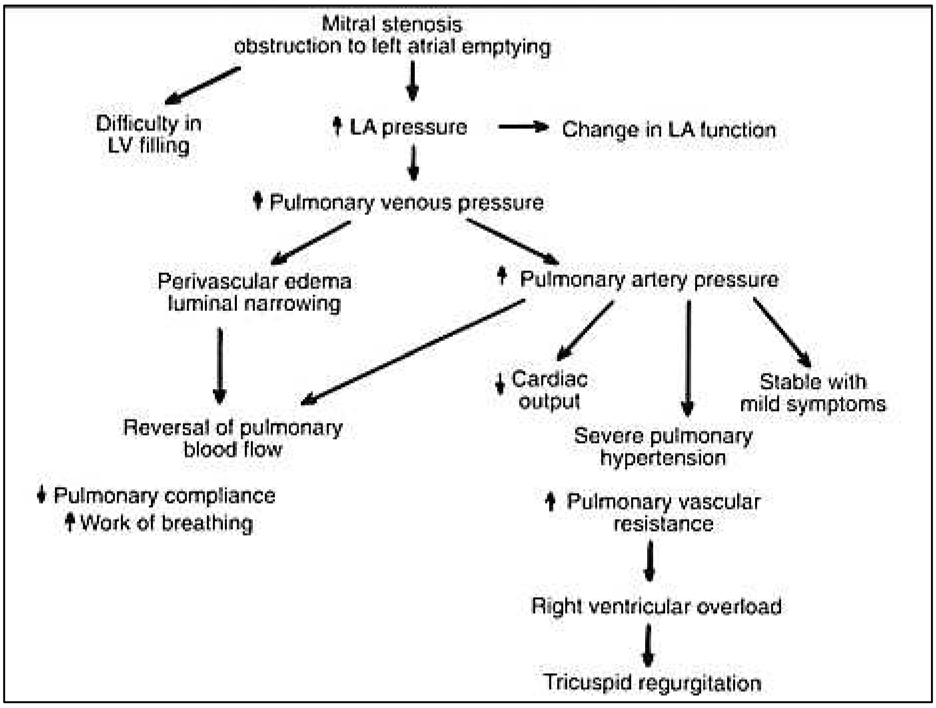


Figure 3.1: Pathophysiology of Mitral Stenosis [6]

Rheumatic heart disease detection requires careful segmentation of mitral valve. Segmentation is a process in which a desired part is separated out of whole space. On the whole segmentation techniques are subdivided into two main groups: region based and edge based. Researchers has developed serval techniques for both of the classes. It is not necessary to blind knowledge in two fix classes. There are other perspectives too. Such as a primary parameter could be intensity, intensity derivative and distribution, texture, phase and shape or combining these parameters together. There are techniques to consider image plane as continuous plan or discrete domain.

Algorithms based on deformable model could be placed into a continuous plane while discrete domain may include nodes, graph cuts. People have worked on several segmentation techniques to get the best result. There are several manual algorithms, semi-automatic algorithms and fully automatic algorithms for the segmentation of mitral valve. Table 3.1 describe the summary of the work done by researchers to get image information for mitral valve.

Table 3.1: Summary of work done by authors for mitral Echocardiography

Author	Year	Work
Bo Remenyi , N Willson [8]	2012	Guidelines for echocardiographic diagnosis of RHD and three classification have seen in this work: ‘Definite RHD’, ‘borderline RHD’ and ‘normal’
Ahmed Omran, Ahmed A Arifi [9]	2011	Most suitable view for mitral valve access is parasternal long axis (PLA)

After getting an appropriate visual information about mitral valve. Sometimes there is noise in the images which can deviates results from ground truth and provide false information. Such as there is speckle noise: speckle noise decreases the quality of images. Low contrast and intensity in-homogeneities makes segmentation a challenging task.

There are two main types of active contours initialization: manual and automatic. Manual needs extra set of care as there is an operator checks each and every inputs but it could result good results. Automated segmentation do not requires an operator checks all the information and provide result. Both manual and automated segmentation techniques can produce best or worst result, it depends on the situation and information provided to the software.

An active contour [10] is a model of deformable curve in a continuous domain whereas in discrete domain set of image points or control points are connected by rod are used to segment the required portion.

Initially level set methods were used for tracking algorithms and computing shapes [11] but with time it I used as segmentation purpose. In level set zero level set is represented by a contour for higher dimension function. There is no need of parameterization for the calculation as it includes fixed grid points for numerical computations.

Level set methods may vary according to need of the application such as it include edge base, region base, intensity based segmentation. But it is difficult to cater for image intensity in homogeneity for a region. Table 3.2 summarizes the existing techniques for image segmentations regarding level set and active contour.

Table 3.2: Image Segmentation Techniques for Heart Mitral Valve

Author	**Year**	**Technique**
Mumford [17]	1989	Level set method based on piece-wise smooth(PS)
T Chan [18]	2001	Piecewise constant (PC) model for level set segmentation
Boykov [19]	2001	Improving level set segmentation incorporate with shape of art using graph cut.
Greg Slabaugh [7]	2005	Graph cut method based on general shape ellipse
D Freedom [20]	2005	User defined shape templates using graph cuts methods
Chumming li [21]	2010	Distance regularized level set evaluation
Chan vese [22]	2002	Active contours without edges
Haifeng li [23]	2014	Adaptive level set segmentation
Hui Wang [24]	2014	Use of local and global Gaussian distribution fitting energies for active contour model
Bin Wang [30]	2014	A level set method using shape priors by using locality preserving projections
Nuseiba [28]	2015	A modified distance regularized level set model for liver segmentation from CT images.

D. Selvati [29]	2016	Phase Based Distance Regularized Level Set for the Segmentation of Ultrasound Kidney Images.
Xialoliang [31]	2017	Level Set Based Hippocampus in MR images with improved region growing method
Agustinus [32]	2017	Deep convolutional level set for image segmentation
Junfeng [33]	2017	A novel level set method for image segmentation by combining local and global information.
Chuin [34]	2018	3D tumor segmentation using 3D weighted level set model
Dengwei [35]	2018	Inhomogeneous image segmentation using efficient multi scale local binary fitting based level set.
Ruben, Ana[36]	2018	Level set segmentation of footprint images aimed at insole design
Wansuo [37]	2019	Image segmentation with shape descriptors in level set model

Altarawneh [28] introduces new balloon force along with traditional DRLSE. This force controls the direction of the evolution curve in right direction and slowdowns the evolution along the path of weak edges in order to reduce the effect of over evolution.

D. Selvathi[29] uses the concept of monogenic signals in order to extract local features like phase, textures, energy and amplitude. Log Gabor function have been used in previous work but this uses Cauchy function for construction of monogenic signals.

Xialoliang[31] uses the concept of adaptive region grow and morphological operations on region of interest for detection of disease hippocampus and combine this initial result with level set method and initialize zero level set contour. Use of gradient decent method to get the minimization of energy term in the level set formulation.

Segmentation algorithms results in subdivided part of image. Next step is to extract the thickness profile of anterior mitral valve leaflet [26]. This process involves several steps and algorithms like thinning, spline modelling, and curvature calculation [27].

Level set model based segmentation by Wang [38] used Gaussian Mixture Model and spilt Bregman. It includes pre-calculation of intensity fitting functions before curve evolution. This step aids curve evolution process as it will avoid add extra numerical effort of updating the fitting functions and also it will not require re-initializations at each iteration. Wang has used Global Convex segmentation and spilt Bregman for the calculation process. Bregman process produces a quick solution (converging) using the idea of level set iterations.

Level set segmentation is an efficient method to segment medical images but the computations increases when there is intensity inhomogeneity is more [44]. It even count a local minima instead of full segmentation. For blurry boundaries and noise issue region based level set is used by Lin [44]. It includes a combination of multi scale local binary fitting along with Kullback-Leibler divergence. This calculation process is more vigorous to initial location of contour.

Region based segmentation includes local information of a particular area such as intensity, color, shape and texture in this scenario active contour will calculate inside and outside energy term. Whereas edge based active contour fails to weak edges. It can include background or left required area unsegmented. Liu [37] proposed a hybrid model for level set segmentation which uses the benefits of both region and edge based segmentation. It includes the sum of energy terms from both cases and test his work on different scenarios. This could result in major complexities too as it could require a large time to compute final result.

Ting Su [55] has used the model of Fractional B Spline level set for segmentation of intensity inhomogeneous images. It includes the concept of level set as a combination of line functions of B Splines. This results in fast calculation of minimum energy term using B Spline coefficients. FBSLS can converge with less iterations which saves a huge segmentation time. The coefficients of FBS can take over the initialization process. FBSLS do not require preprocessing so noise has a very limited effect on segmentation.

A semi-automated level set [69] is used to segment left ventricular in MRI with the integration of top down deep neural network. The advantage of deep belief network is its robustness towards the algorithm with use of very few images. It consists of hierarchal method of calculation which can work in complicated environment as well.

Droskey [59] represented a multigrid level set method for 3D medical image processing. There are several non-sharp and blurry boundaries in medical images so this model includes interactive modulation for speed function.

Ho [60] introduces a software package for level set by applying gradient based and region competition level set methods.

Intensity inhomogeneity in medical imaging is a common issue. It could be due to technical issues or due to the limitation of object under observation, or imaging equipment is not up to mark. In all cases segmentation get affected directly by intensity problem. Region based segmentation [14] in level set environment provides good results. It includes region saleable fitting (RSF) for energy calculation and two other fitting calculations on the inside and outside of the drawn contour. The use of intensity information in a region with controlled parameter could result in the motion of contour at desired location.

In image segmentation process using level set algorithms sometimes develops anomalies or miss guide the contour evolution process and even destroy whole output. To overcome this difficulty Distance Regularized Level Set model [21] intrinsically maintain its curve evolution process. An external energy term is calculated which force the curve to move to desire position. Whereas regularization term is defined as a potential function which uses the effect of forward and backward diffusion. This process will excludes the need of initialization on regular basis.

Image segmentation is an important task for object recognition, volume estimation, object classification or detection. Level set method mainly used to overcome the problem of shapes and intensity. Level set methods have several advantages over segmentation techniques such as this process could be semi-automated or fully automated, it do not requires parameterization of contour, as compared with snakes level set methods are less sensitive to noise, it can include higher dimensions, this is more flexible to topological changes. It can detect sharp corners and edges. It can provide a fare numerical result.

Thickness profile calculation is an important task for a complete segmentation process. It provides numerical results for detection of rheumatic heart disease. In RHD mitral valve change its thickness or shape. Blood flow become difficult. So a precise measurement of anterior of Mitral valve is necessary.

Pires [65] uses the concept of morphological Skeletoniztion and spline modeling in order to get the central line for the segmented part. Four quartiles division is done to calculate the distance from lower to upper boundary.

The World Heart federation [60] have certain criteria to identify the disease. According to WHF tip of mitral valve in diseased cases id thicker than normal cases.

Chapter 4: Proposed Methodology

This section discusses the all phases of our proposed methodology in which each DICOM file is analyzed for the segmentation of mitral valve. From these segmented part physiological parameters are calculated to classify healthy or RHD person. The methodology aims to improve the accuracy of segmented mitral valve.

Figure 4.1 represents the flow diagram for the proposed methodology used in this research.

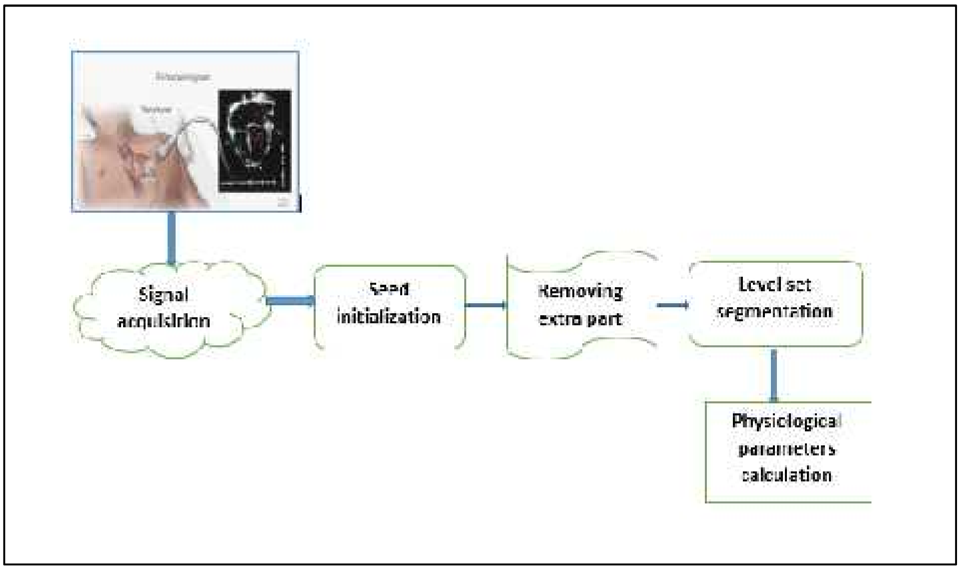


Figure 4.1: System Level Diagram of Proposed Methodology

4.1 Signal Acquisition

Echo-cardiogram is an easy way to collect data for heart Mitral valve. It is noninvasive method. Ultrasound images collected on the basis of heart sound waves called echo-cardiogram. File format we have used in our methodology is DICOM. DICOM is Digital Imaging and Communication in Medicines a standard used worldwide. It is used to for the management and communication of medical imaging information and related data. It is easy to use due to its integration with hardware such as scanners, servers, workstations, printer, network and hardware.

DICOM usually groups information into datasets such as: name tags, patient's age and other attributes which make it easy to get all initial information regarding specific echo cardiogram.

Figure 4.2 shows a visual representation of DICOM file obtained from Echocardiography for heart mitral valve.

Figure 4.1.2 Echo-cardiogram in DICOM format

4.2 Seed Initialization

Next step of our methodology to specify a best position of mitral valve on ultrasound image. As it is a grayscale image and there is intensity in homogeneity trough out the image. There is no define line or harsh breaks for extraction of mitral valve. One has to either train whole data set or feed an initial seed so next step could be possible for segmentation.

Our aim is to identify the location of mitral valve so we can initialize contour in next stage. We have used our knowledge about shape and size of mitral valve. As mitral valve is an eye like structure with two cusps: anterior mitral valve and posterior mitral valve. The PML is a short body structure whereas AML is long, flat valve. We are interested to separate the AML part out of ultrasound.

There are several methods to train a data set like initialization of a specific point or use neural network knowledge to train whole data set on the basis of shape like KNN. We

4.2.1 Algorithm of Seed Initialization

For accurate result, 2 D coherent structure tensor are calculated. The computation involves sum of images gradient with Gaussian window w(x, y) at different orthogonal directions. Equation (4.2.1) below represents the discrete structure tensor.

$$S(x,y) = \begin{bmatrix} i_x\ (x,y) & i_x\ (x,y) \\ i_y\ (x,y) & i_y\ (x,y) \end{bmatrix} \quad (4.2.1)$$

$$i_x\ (x,y) = \sum_{\cdot x\ \in w} \sum_{\cdot y\ \in w} w(x_i, y_j) \frac{(\partial \quad (x-x_i, y-y_j))^\wedge 2}{\partial} \qquad (4.2.2)$$

$$i_x\ (x,y) = i_y\ (x,y) = \sum_{\cdot x\ \in w} \sum_{\cdot y\ \in w} w(x_i, y_j) \frac{(\partial \quad (x-x_i, y-y_j))^\wedge 2}{\partial} \frac{(\partial \quad (x-x_i, y-y_j))^\wedge 2}{\partial} \qquad (4.2.3)$$

$$i_y\ (x,y) = \sum_{\cdot x\ \in w} \sum_{\cdot y\ \in w} w(x_i, y_j) \frac{(\partial \quad (x-x_i, y-y_j))^\wedge 2}{\partial} \qquad (4.2.4)$$

S(x, y) in equation 4.2.1 represents tensor matrix. In this Matrix $i_x\ (x, y)$ is horizontal tensor. We get this horizontal tensor by convolving the horizontal gradient with Gaussian window w(x, y). Similarly$i_x\ (x, y)$ and $i_y\ (x, y)$ is the output of convolution of w(x, y) with sum of product of horizontal and vertical gradients. Whereas $i_y\ (x, y)$ is vertical tensor and it can be found by convolving w(x, y) with vertical gradient. De-noised image is the output of this process.

Algorithm 1: Initialization of Seed

1. **Procedure**
2. **Input**: Images
3. **for** each image **do**
4. 2D pre-defined Gaussian low pass filter
5. 2D FIR filter
6. Calculation of structure tensor matrix
7. Ridges Calculation
8. Binary Conversion
9. Remove small object (connected components)
10. Calculation of midpoint
11. 3x3 padding of midpoint
12. **end**

Figure 4.2.1.1: Binary Image with Initial Seed

4.3 Removing Extra Information

In second step of proposed method is to remove information that can destroy the evolution of curve. There are methods to remove noise or unwanted information like neural network. We have developed an easy way in which user can eliminate the part of image on hand. As level set formulation in next step can vary due to sharp intensity element present near mitral valve. We certainly do not want our evolution of curve to deviate from required path. So we have used 2 manually initiated rectangles to remove information that we do not required.

4.3.1 Steps to remove unwanted information:

In order to remove such extra part of image we have drawn two rectangles on image. Shape could be of any type but we have choose rectangle as it will provide end points [Xmin Ymin width height]. Assigning 0 to intensity in this pixel range will convert noisy or extra part in back ground part that is black in our case,

Figure down below shows a clear difference between and input image and remove part of unwanted information.

Figure 4.3.1 (a) Input image with no preprocessing, (b) image with removed information in upper part.

4.4 Image Segmentation

Due to acute episodes of rheumatic fever mitral valve tends to narrow down and low resistant to blood back flow results in mitral stenosis. In this step of proposed methodology we have used a segmentation algorithm using preexisting segmentation techniques that is level set segmentation. In level set evolution firstly a zero level contour is initiated manually on image. Conventional level set algorithms have tendency to develop irregularities so they need re-initialization on each step. Process of re-initialization is computational complex and may cause numerical errors. So we have used the algorithm of Distance Regularized Level Set. DRLSE maintain its curve evolution intrinsically.

We have developed the idea of autonomous evolution of curve on an image. For this purpose we have selected a seed point in section 4.2 and combine this knowledge with existing DRLSE algorithm to generate an automatic segmentation technique for mitral valve extraction out of whole image.

4.4.1 Steps for segmentation

Algorithm 2: Segmentation

```
Procedure: Distance Reguarized Level Set
 for: run for all images
     conversion in double precision
```

4. Initailzation of contour $\frac{\partial \ (s,t)}{\partial} = F$ on selected seed pixel in 4.2.1

5. Call energy funtion $\varepsilon(\phi) = \mu \quad (\phi) + \varepsilon \quad (\phi)$

6. Set initail conditions time step, alpha,mu , coefficeints of weighted length term lamda

7. **for** initailze iterations

8. Guassain smoothing

9. Edge indicator

10. Contraction of initail contour in sahpe

11. end

12. Adding extra refining iterations

13. Mesh calculation for final contour

14. end

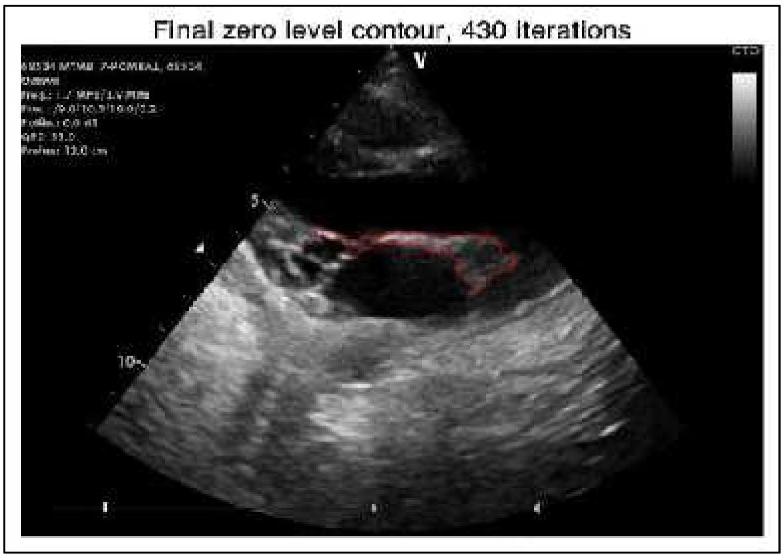


Figure 4.4.1 Final output of segmentation result

4.5 Calculation of physiological parameters

Valve thickness is an important part of diagnosis Rheumatic Heart Disease, manual calculation needs more man power, highly trained technicians, professional people and most important time. The solution is automated screening of segmented parts and generation of thickness profile. It will also eliminate the risk of two different observation as in manual screening if two or more people work on same segment results will be different.

This section will cover an automated algorithm for calculation of thickness profile. Results obtained in section 4.4 needs to quantify, measure and analyze the thickness of anterior of mitral valve. Main idea is to divide segmented part obtained previously into three quartiles: tip mid and tail. Algorithms are applied to find thickness of each quartile automatically. Aim of this section is to reduce the need of trained and professionals to analyze echocardiogram and make it a feasible solution for developing countries like Pakistan.

Our proposed methodology can be represented as follow

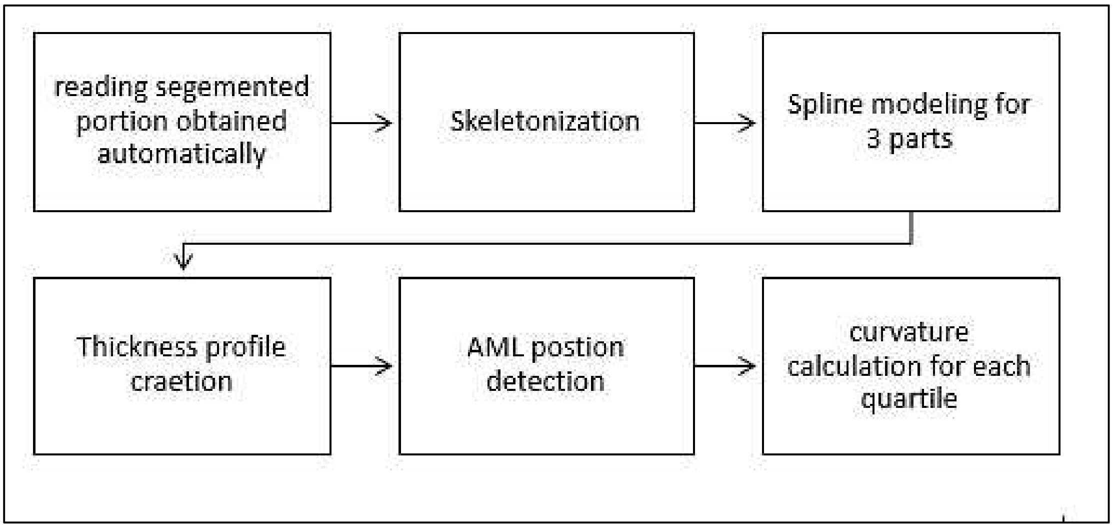


Figure 4.5 Flow chart of Proposed Methodology for Curvature Calculation

4.5.1 Steps involved in calculation of physical parameters:

The goal of this research is to generate an algorithm that can differentiate a healthy mitral valve and unhealthy mitral valve. We have done segmentation on dataset provided by Portuguese research group. Next process is to draw results on the basis of physical parameters like thickness profile, curvature calculation etc.

World health Federation (WHF) made a criteria which clearly indicate that tip of the valve is thicker in pathological cases as compared with normal valve. But recent studies have shown a remarkable difference that it is the midpoint of the valve that shows more deviation from normal cases.

This section will cover all the necessary steps required to generate a thickness profile of segmented mitral valve automatically. Following the flow chart of proposed methodology in figure 4.5

4.5.1.1 Skeletoniztion

Finding the morphological skeleton is first step to this part of our research. There are several algorithms for fining the skeleton of a segment but we have choose the work of Zhang-Suen [6]. It is important to maintain the required shape of the segment along with all connection and clearly no breaks should be part of this skeleton. It uses the idea of eight neighbor's connectivity and removes unwanted pixels from surroundings.

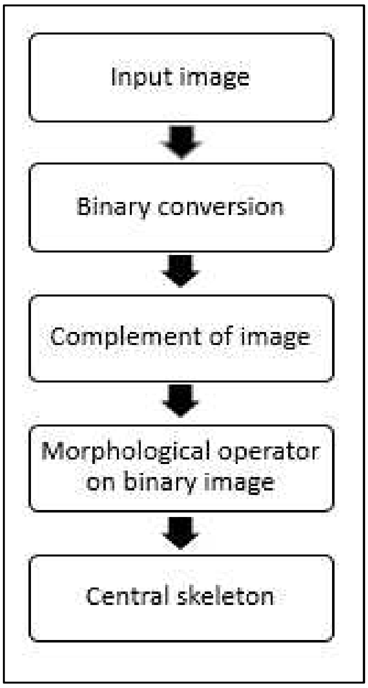


Figure 4.5.1.1: Skeletoniztion Flow Chart

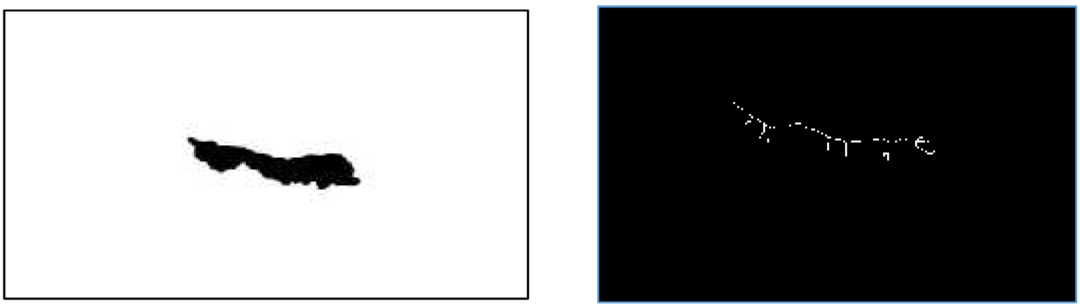


Figure 4.5.1.2 Input Image verses Skeleton of Input Image

4.5.1.2 Spline Modeling

Spline is a flexible curve used to model skeleton of a segment. It consists of two end points passing the skeleton at the normal direction. We have used three quartile method. This three quartile are tip, mid, tail. Our focus is to determine the thickness profile for each quartile. Next step is to find edges of images so an outer boundary is obtained. Local maxima of the gradients of input images will result in the form of edges of images. This process is canny method. Derivative of Gaussian results in gradient. In output we get weak and strong edges. This method is efficient to find weak edges and cannot be fooled even in the presence of noise.

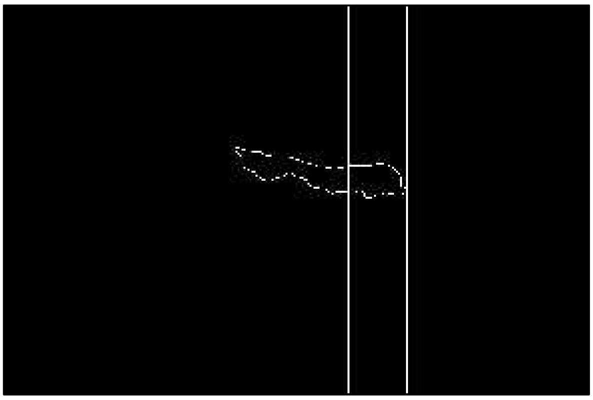


Figure 4.5.1.2.1 Three quartile with Outer Boundary

4.5.1.3 Thickness Profile Generation

We have find the thickness of each quartile by counting the number of pixels in ach part. For tip: find the number of pixels in each column with in the outer boundary. Then find the mean, dividing by the total number of pixels.

We have done conversion of this mean pixel value in more readable form. So a pixel to centimeter conversion is done in this step. We find the dpi (dots per inch) values for our system then multiply this pixel value to standard centimeter number.

For 96 dpi:

1pixel = 0.0265cm

Chapter 5: Results and performance Evaluation

Introducing automated methods in the fields of medical imaging is very critical. The technique implemented should be capable enough to detect and diagnose the disease correctly to give minimum error rate. It is really important to test and validate the results of the algorithm properly before making it available commercially. It is an important practice to verify results by proper medical specialists. Therefore, for the verification of our algorithm we compare our results with the results provided by radiologists. This chapter discusses the dataset we have used to implement our algorithm. We compare our results by manually segmented results using dice similarity coefficients, and curvature calculation for cross validation. We compare our results with the technique implemented in [20].

5.1 Dataset

Ultrasound imaging, being the one of the trend of detecting many valvar disease, is used for the detection of rheumatic heart disease. Ultrasound image of heart is echocardiogram, it provides the cross sectional view of heart' valve makes more useful to detect early signs of mitral stenosis or rheumatism as compared with other imaging technologies. It is noninvasive, painless, easy to use and portable.

Dataset used in this research is not publically available. Data set used in this task is provided by the Real Hospital Portuguese, in Recife, Brazil. It consists of 4 mp4 file format ultrasound videos and DICOM videos of their patients. DICOM files provides information about patient and imaging technology over tags joined in this videos. Figure below represents a DICOM static image with few tags like what frequency this video was taken, QPS factor, date, time etc.

The data was collected by M Turbo model by SonoSite ultrasound system with C11x transducer (5-8 MHz). The dataset used in this research consists of 5 different cases that are: slow moving leaflet, fast moving leaflet, elongated leaflet, thick/thin leaflet.

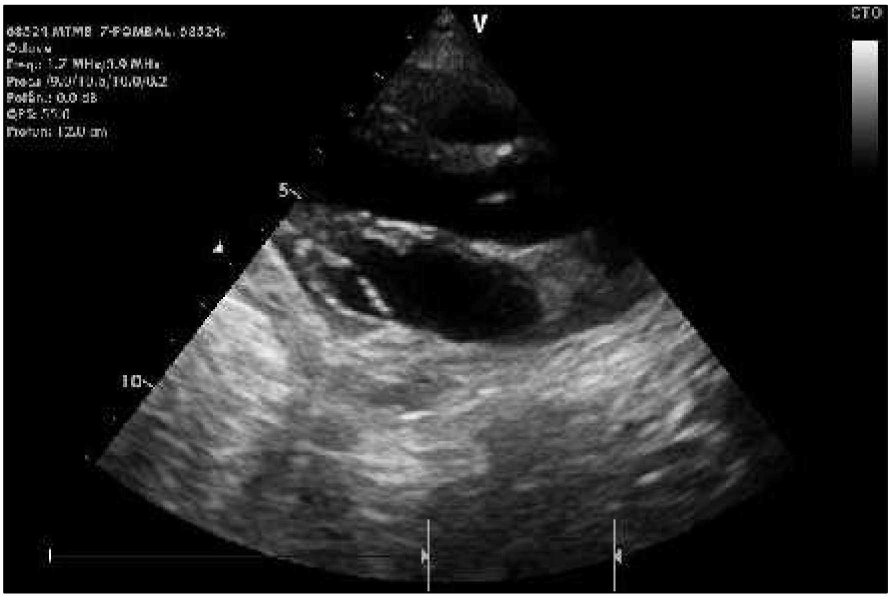


Figure 5.1.1: DICOM Image with Tags

5.2 Module

This research work is done on MATLAB. As it provides an extensive library and preexisting functions.

5.3 Performance Parameters:

The performance parameters we have used in this research work is Dice similarity coefficients and curvature calculation.

DSC is used to gauge the similarity between to samples. It is the measurement of a specific region equation (5.3) represents the expression for DSC

$$D\quad (\imath\ 1, \imath\ 2) = \frac{2|\imath\ 1 \cap \imath\ 2\,|}{|\imath\ 1|+|\imath\ 2|} \qquad (5.3)$$

Where image 1 and image 2 provides information in discrete form.

Figure down below shows a comparison of manual segmented mitral valve and automatically segmented mitral valve.

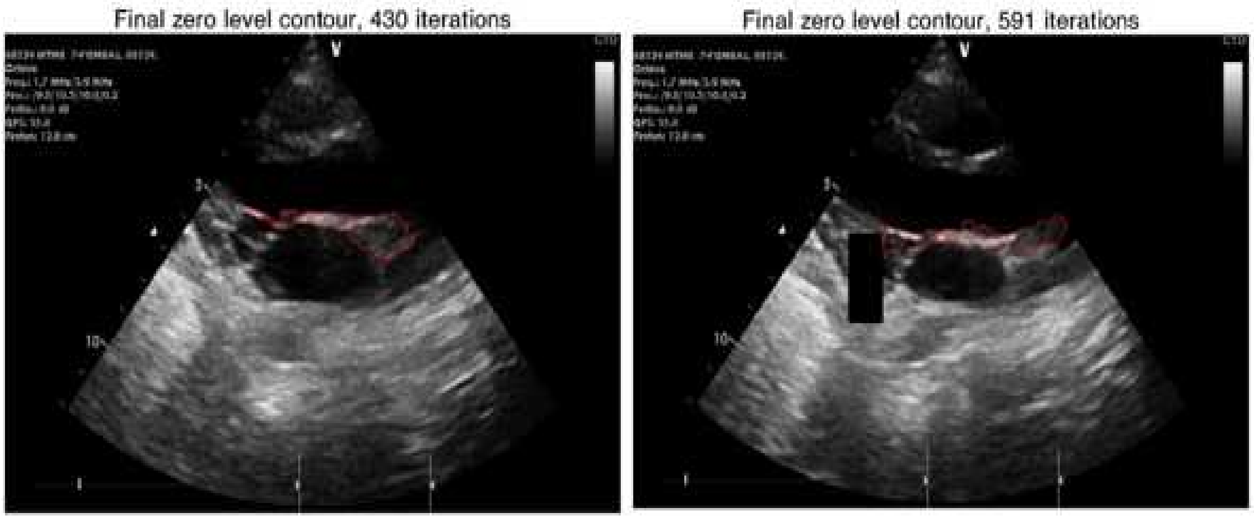


Figure 5.3.1: a) manual segmentation result verses b) automatic segmentation

Figure below is a presentation of DSC output, in which two of the images: automatic segmented image 1 is overlapped with a mask of manual segmented image. Output of image number 67

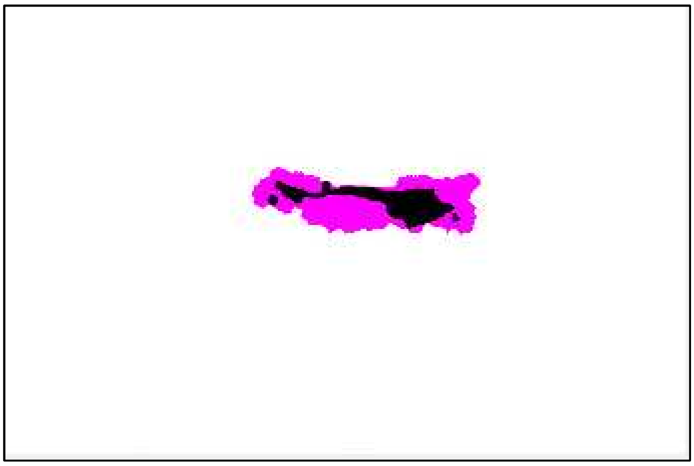


Figure 5.3.2 DSC Output

5.3.1 Folder DICOM:

Table 5.3.1 represents a complete result of Dice similarity coefficient of DICOM file 1. In this data set there are total 91 frames. Dimension of each frame is 422x636. A manual screening is done to identify open positions of the valve. There are total of 5 frames in the open position of mitral valve. Whereas 18 frames represents straight position. 68 frames shows open to close and close to open position. In this state valve shows a clear merging of its edge with PML. There is no clear cut boundary due to low contrast so the risk of wrong segmentation is high.

<u>Frames with open Valve:</u>

i. Frame 15
ii. Frame 16
iii. Frame 35
iv. Frame 54
v. Frame 55

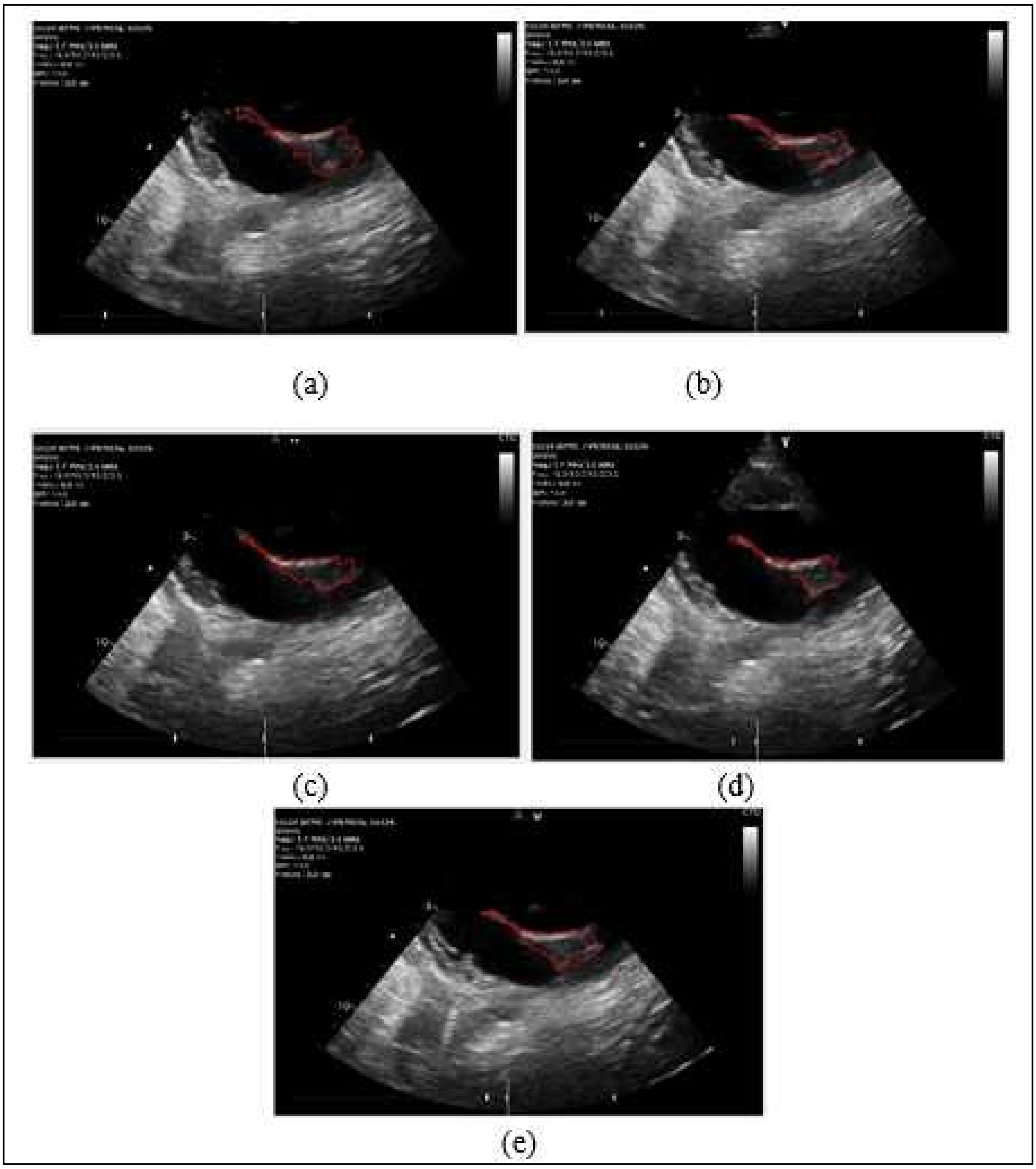


Figure 5.3.1.1 (a) Frame 15, (b) Frame 16, (c) Frame 35, (d) Frame 54, (e) Frame 55, Automatic Segmentation result

There is a clear result of DSC in the table 5.3.1. These frames represents values close to 1 which is an indication of good matching between manually segmented valve and automatically segmented valve. DSC is independent of position of the valve as it is a similarity index between two images. Frame 52 for example is a straight position of the valve but shows a high DSC value.

Figure 5.3.1.2: (a) Frame 52 Manually Segmented, (b) Frame 53 Automatically Segmented

Table 5.3.1 Dice Similarity Coefficients for Video 1(90 frames)

Frame number	DSC	Frame number	DSC	Frame number	DSC
1	0.6688	31	0.99	61	0.65
2	0.5954	32	0.5745	62	0.5167
3	0.5169	33	0.6691	63	0.59
4	0.6099	34	0.6498	64	0.2725
5	0.4566	35	0.95	65	0.07
6	0.3998	36	0.6499	66	0.5450
7	0.5021	37	0.6736	67	0.86
8	0.5499	38	0.6305	68	0.6082
9	0.5707	39	0.66	69	0.74
10	0.4754	40	0.41	70	0.69
11	0.6096	41	0.01	71	0.3322

12	0.6715	42	0.6135	72	0.09
13	0.734	43	0.45	73	0.3443
14	0.499	44	0.5225	74	0.813
15	0.88	45	0.358	75	0.6107
16	0.89	46	0.6489	76	0.47
17	0.4839	47	0.12	77	0.30
18	0.5455	48	0.5896	78	0.6070
19	0.3901	49	0.4938	79	0.3023
20	0.5924	50	0.5102	80	0.0872
21	0.59	51	0.20	81	0.3102
22	0.5903	52	0.94	82	0.0601
23	0.6708	53	0.4866	83	0.2301
24	0.5061	54	0.69	84	0.611
25	0.4987	55	0.69	85	0.6178
26	0.75	56	0.3102	86	0.087
27	0.5393	57	0.5927	87	0.0223
28	0.63	58	0.5821	88	0.3201
29	0.6154	59	0.5821	89	0.54
30	0.6608	60	0.62	90	0.5871

Table 5.3.2 Thickness Profile in cm for Video 1

Frame No:	**Thickness Profile in cm**		
	Tip	Mid	Tail
1	0.4849	0.4377	0.212
2	0.2144	0.2487	0.1855
3	0.2018	0.3125	0.159
4	0.212	0.4184	0.159
5	0	0	0
6	0	0	0
7	0.3397	0.5688	0.3445
8	0.24	0.2592	0.323
9	0	0	0
10	0.2255	0.2599	0.371
11	0.2091	0.358	0.2385

12	0.249	0.4739	0.5035
13	0	0	0
14	0	0	0
15	0.4333	0.7646	0.6095
16	0.4672	0.6659	0.3445
17	0.4063	0.5633	0.234
18	0.2264	0.5053	0.2517
19	0.225	0.6201	0.265
20	0.1855	0.5352	0.234
21	0.1684	0.4289	0.22
22	0.1481	0.2966	0.22
23	0.3472	0.4936	0.159
24	0	0	0
25	0	0	0
26	0	0	0
27	0	0	0
28	0.2623	0.439	0.22
29	0	0	0
30	0	0	0
31	0	0	0
32	0	0	0
33	0	0	0
34	0.3454	0.3317	0.22
35	0	0	0
36	0	0	0
37	0.2746	0.2484	0.159
38	0.2086	0.3628	0.106
39	0.378	0.3043	0
40	0.3251	0.4905	0.2517
41	0.199	0.6253	0.22
42	0.3323	0.4501	0.22
43	0.2286	0.4121	0.212
44	0.156	0.4405	0.1457
45	0.2374	0.5272	0.1325
46	0.2032	0.4327	0.1722

47	0.1964	0.3107	0
48	0	0	0
49	0.1567	0.3834	0
50	0.1601	0.4739	0.1325
51	0.1569	0.2416	0.1325
52	0	0	0
53	0	0	0
54	0	0	0
55	0	0	0
56	0.217	0.2508	0.159
57	0.3067	0.4116	0
58	0.3185	0.4098	0
59	0.2703	0.3671	0
60	0.2744	0.3245	0.212
61	0	0	0
62	0	0	0
63	0	0	0
64	0.2709	0.3874	0.22
65	0	0	0
66	0.1489	0.4813	0.22
67	0.2556	0.2919	0.1325
68	0.308	0.2684	0
69	0.1933	0.2726	0.159
70	0	0	0
71	0	0	0
72	0	0	0
73	0.1696	0.4682	0.22
74	0.2931	0.3511	1.0335
75	0.2764	0.3424	1.06
76	0.253	0.3746	0.1325
77	0.343	0.2496	0.2253
78	0	0	0
79	0	0	0
80	0	0	0
81	0.479	0.3826	0.212

82	0	0	0
83	0	0	0
84	0	0	0
85	0.1788	0.2478	0.159
86	0.1855	0.2872	0.1325
87	0	0	0
88	0	0	0
89	0	0	0
90	0	0	0
91	0.1703	0.2744	0.23

5.3.2 Folder 49760:

This folder consists of video of mitral valve. The duration of mp4 video is 6 seconds and it consists of 359 frames in total. Table 5.3.2 represents a DSC calculation for first 90 frames. Manual screening results in 32 open positions of mitral valve. Dimension for each frame is 480x640.

Table 5.3.2.1 Dice Similarity Coefficients for video 12.53.51 horas __[0000618] (1st 90 frames)

Figure number	DSC	Figure number	DSC	Figure number	DSC
1	0.8507	31	0.8147	61	0.3500
2	0.5606	32	0.9058	62	0.1966
3	0.9296	33	0.1270	63	0.2511
4	0.6967	34	0.9134	64	0.6160
5	0.5828	35	0.6324	65	0.4733
6	0.8154	36	0.0975	66	0.3517
7	0.8790	37	0.2785	67	0.8308
8	0.9889	38	0.5469	68	0.5853
9	0.0005	39	0.9575	69	0.5497
10	0.8654	40	0.9649	70	0.9172
11	0.6126	41	0.1576	71	0.2858
12	0.9900	42	0.9706	72	0.7572
13	0.5277	43	0.9572	73	0.7537

14	0.4795	44	0.4854	74	0.3804
15	0.8013	45	0.8003	75	0.5678
16	0.2278	46	0.1419	76	0.0759
17	0.4981	47	0.4218	77	0.0540
18	0.9009	48	0.9157	78	0.5308
19	0.5747	49	0.7922	79	0.7792
20	0.8452	50	0.9595	80	0.9340
21	0.7386	51	0.6557	81	0.1299
22	0.5860	52	0.0357	82	0.5688
23	0.2467	53	0.8491	83	0.4694
24	0.6664	54	0.9340	84	0.0119
25	0.0835	55	0.6787	85	0.3371
26	0.5489	56	0.8147	86	0.3500
27	0.8507	57	0.9058	87	0.1966
28	0.5606	58	0.1270	88	0.2511
29	0.9296	59	0.9134	89	0.6160
30	0.6967	60	0.6324	90	0.7023

5.3.3 Folder 49653:

This folder consists of mp4 video of duration 2 seconds. It has total 65 images. Dimension for each frame is 480x640. This video represents a fast moving mitral valve. This information could be used for a long way tracking after segmentation.

The mitral valve is efficiently segmented using Distance Regularized Level Set methods which is shown in the figures below.

(a)

(b)

(c)

(d)

(e)

Figure 5.3.3: a) Frame 1 **b**) Frame 5 **c**) Frame 11 **d**) Frame 47 **e**) Frame55

Table 5.3.3 represents the thickness profile measured after segmentation step. As this video clip has more blurry boundary some of the frames missed calculation due to more than one contour in the final step of segmentation.

Table 5.3.3: Thickness Profile for folder 49653

Frame No:	Thickness Profile for data set 49653 in cm		
	TIP	MID	TAIL
1	0.1590	0.4437	0.2120
2	0.1725	0.4684	0.2013
3	0.1958	0.4847	0.3012
4	0	0	0
5	0.1681	0.6544	
6	0.1541	0.4288	0.1325
7	0.1619	0.5047	0.2313
8	0.1688	0.4654	0.3342
9	0.1783	0.2773	0.3421
10	0.2084	0.4002	0.2253
11	0	0	0
12	0	0	0
13	0.1783	0.5612	0.1325
14	0.3001	0.8745	0.3421
15	0.2943	0.8734	0.4325
16	0.1567	0.5190	0.1060
17	0	0	0
18	0	0	0
19	0.1601	0.4547	0.4505
20	0.2865	0.6135	0.5143
21	0.6785	0.4308	0.2253
22	0.1633	0.3228	0.2313
23	0.2057	0.3687	0.2253
24	0.2148	0.3537	0.4770
25	0.1878	0.4146	0.4505
26	0.2718	0.3679	0.1325
27	0.1949	0.3623	0.2253
28	0.2078	0.3690	0.4108
29	0.1618	0.5007	0.1325
30	0.1860	0.7425	0.4538

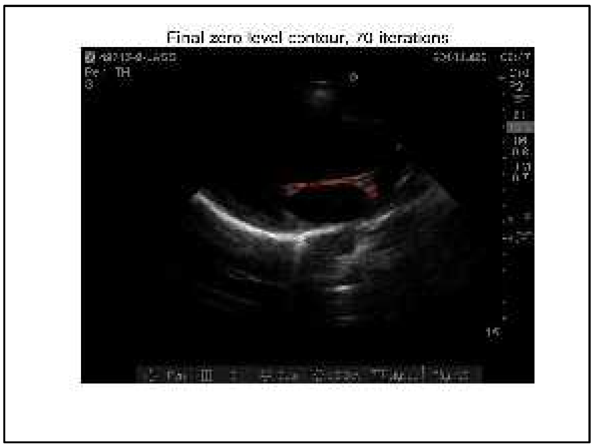
31	0.1579	0.5604	0.2385
32	0	0	0
33	0.2028	0.5201	0.4323
34	0.1982	0.3396	0.2354
35	0.1875	0.3941	0.2385
36	0.1564	0.2910	0.3562
37	0	0	0
38	0	0	0
39	0.1683	0.4415	0.4432
40	0.1445	0.4363	0.2650
41	0.1632	0.4141	0.2123
42	0.1430	0.5186	0.3180
43	0.1643	0.5274	0.3975
44	0.1872	0.5215	0.2120
45	0.2024	0.4753	0.1457
46	0.1543	0.3076	0.1060
47	0.1872	0.4150	0.1060
48	0.1897	0.4593	0.2343
49	0.1659	0.3919	0.2915
50	0.1633	0.3228	0.1560

5.3.4 Folder 49713:

This folder consists of mp4 of 2 seconds. There are total 65 frames of dimension 480x640. This video depicts an elongated leaflet. There are total of 10 open positions. While segmentation for this folder shows abrupt results as it may divide final contour into multiple segments. This is not a desirable result as it will not calculate thickness profile automatically and generate error in the last step.

Figures below explain some of the good and bad results of folder 49713.

(a) **(b)**



(c) **(d)**

(e) **(f)**

Figure 5.3.4: a) Frame 1 (good result) b) Frame 8 (Bad result) **c)** Frame34 (Bad result) **d)** Frame 50 (good result) **e)** Frame 55 (good result) **f)** Frame 28 (Bad Result)

Table 5.3.4.1 down below represents the results calculated for each frame in folder 49713. Frames with NaN shows the segmentation is not in the form of single contour. So there is error for automatic calculation for thickness profiles for these specific frames. Manual calculations are still not enough for physiological parameters as multiple contours represents breaks and do not include required portion.

Table 5.3.4.1: Thickness profile for folder 49713 in cm

Frame No:	Thickness Profile for data set 49713 in cm		
	TIP	MID	TAIL
1	0.1469	0.1421	0.1192
2	0	0	0
3	0.1389	0.1422	0.2782
4	0.1313	0.1645	0.1987
5	0.1362	0.1740	0.1325
6	0.1315	0.1659	0.1590
7	0.1325	0.1787	0.1855
8	0	0	0
9	0.1315	0.1511	0.1590
10	0.1537	0.1737	0.2120
11	0.1286	0.1363	0.1590
12	0.1283	0.1356	0.1855
13	0	0	0
14	0.1254	0.1368	0.1060
15	0	0	0
16	0.1286	0.1394	0.1325
17	0.1272	0.1450	0.3180
18	0.1419	0.1863	0.1233
19	0.1408	0.1391	0.1590
20	0.1469	0.1929	0.1060
21	0	0	0

22	0.1531	0.1647	0.3842
23	0.1410	0.1570	0.1590
24	0.1404	0.1476	0.1060
25	0.1549	0.1580	0.1233
26	0.1410	0.1468	0.1060
27	0.1335	0.1921	0.1134
28	0	0	0
29	0	0	0
30	0.1283	0.1420	0.1192
31	0.1260	0.1388	0.0795
32	0	0	0
33	0.1405	0.1494	0.3975
34	0	0	0
35	0	0	0
36	0	0	0
37	0.1259	0.1584	0.5697
38	0.1345	0.1583	0.1855
39	0	0	0
40	0	0	0
41	0	0	0
42	0	0	0
43	0.1257	0.1789	0.3975
44	0	0	0
45	0	0	0
46	0	0	0
47	0	0	0
48	0.1549	0.2306	0.1457
49	0.1628	0.2230	0.1564
50	0.1349	0.2112	0.1722

5.4 Characteristics Effecting Results

There are several factors that directly effects curve evolution of Distance Regularized Level Set. Some of these factors are:

1. High Contrast
2. Low Contrast
3. Doppler characteristics

5.4.1 High Contrast

High contrast means image have intensity more in the gray intensity level. High contrast images have strong boundaries and edges and the segmentation of a strong edge is easy. Few iterations can identify the region of interest easily. It prominently allows algorithm to focus on the anterior mitral valve for segmentation purpose. In dataset given DICOM file shows a high contrast video. So the results for manual and automatic segmentations are well defined.

5.4.2 Low Contrast

Low contrast means image have intensity level not in a gray range. There are weak edges and boundaries. There is no clear cut difference between region of interest and background. This issue directly effects the output of DRLSE and not allowing algorithm to evaluate exact leaflet. Video 49760 is a low contrast video.

5.4.3 Doppler Characteristics

The Doppler characteristics of echocardiography results in a low contrast videos which results in miscalculation of automatic segmentation of anterior mitral valve.

World Heart Federation established in 2012 define a criteria and provide guidelines to identify definite RHD cases. According to WHF RHD criteria vary from age to age but must meet these criteria defined below:

I. Anterior Mitral Valve thickening greater and equal to 3mm (age specific)
II. Chordal thickening
III. Velocity of valve greater or equal to 3m/s
IV. Jet length greater or equal to 2cm

We have developed the algorithm for the automatic segmentation of mitral valve and calculated the AMVL thickness on each frame of provided dataset.

Accuracy measurement is 80.2 % using the values of dice similarity coefficients and curvature of DICOM file. Table 5.3.2 shows mitral valve's tip and middle portion are more thick on the opening and straight positions meeting the 3mm threshold in pathological cases visibly.

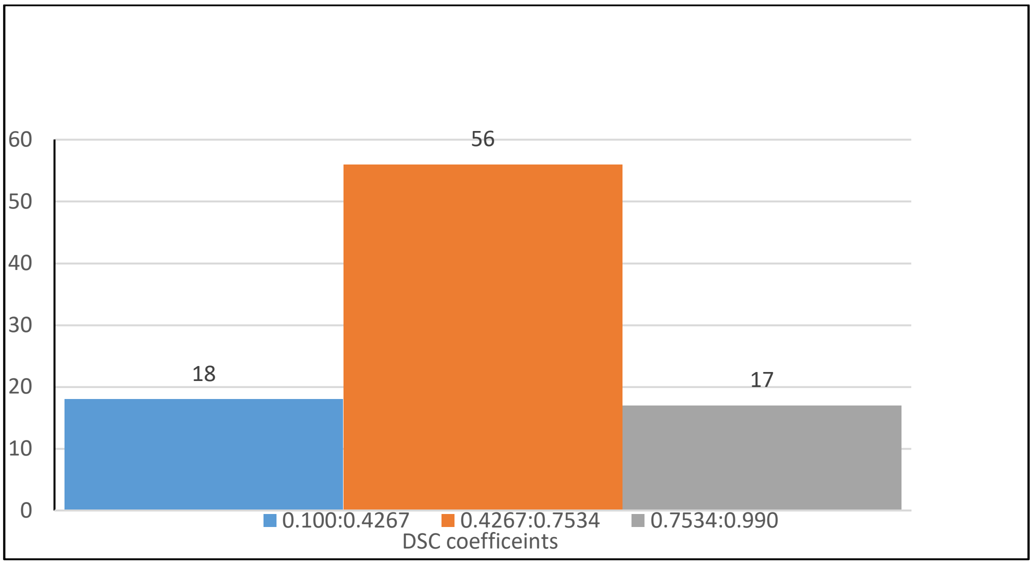


Figure 5.4: Histogram using DICOM file

Chapter 6: Conclusion and Future Work

6.1 Conclusion

A fully automated method is proposed for the segmentation of heart's mitral valve using DRLSE. The segmented valve is then evaluated for detection of rheumatism. Echocardiogram is used widely for the detection of different cardiovascular diseases. For accurate and on time diagnosis of cardiovascular disease like rheumatic heart disease is very crucial. This research contributes in automatic segmentation of heart mitral valve using the knowledge of Distance Regularized Level Set segmentation. A speed function is made in order to extract the boundary of the valve. It enables to remove unwanted information that can change the shape of contour. Results found using this segmentation technique is compared with the result generated by experts and quantitative measurements are made.

Results have been compared with the WHF criteria. It was an early diagnosis that only tip is considered as the main part for calculation of curvature and detection of rheumatism but recent work and WHF pathological cases have shown both tip and mid part should be taken into account for rheumatism detection.

Table 6.1: Curvature evaluation for DICOM data with automatic segmentation

	Curvature using Auto segmentation		
	open	straight	Close
Tip	0.50862	2.385	4.5429
Mid	0.69354	4.2088	3.6018
Tail	0.2654	2.7665	6.7746

Table 6.2 represents the curvature calculation using manual segmentation [65]. Pires have calculated AMVL thickening values with manual segmentation and manual Skeletoniztion method.

Table 6.2: Curvature evaluation for DICOM data using manual Segmentation [65]

	Curvature using Manual segmentation		
	open	straight	Close
Tip	1.13	0.82	0.78
Mid	0.81	0.25	0.36
Tail	0.30	0.22	0.36

6.2 Future Work

This research work further can be improved by integration of features extraction along with intensity based DRLSE and using machine learning state of art technique like neural network, particle swam optimization etc. Phase based segmentation techniques can be applied to get useful results. Balloon forces can be added in DRLSE which can discourage the evolving contours which exceeds the boundary with a weak edge.

3D segmentation is also plays an important role for exact location of change of thickness of mitral valve.

Training data set using neural network algorithms before segmentation can help a lot and improve the quality of whole process with less error. As it can find open, close and mid position of valve before actual segmentation algorithm so there will be no need of static contours.

For a complete diagnosis of RHD mitral valve tracking should be included to meet WHF criteria for RHD.

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