Automatic Liver Segmentation and Visualization for CT Images

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Date: 5 June 2016

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Major: Software Engineering

Date of Defense: 2016-10-05

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Acknowledgments

Firstly, I would like to thank my supervisor Dr. Professor Hong Song for helping to assess my thesis subject and giving me significant advice and feedback during the implementing and writing of my thesis project.

Also it is a pleasure to be student of Dr. Professor Harold Liu, Dr. Professor Che Haiying, Dr. Professor Gao Guangyu, Dr. Professor Shang Jianyun and another revered teachers.

I would like to thank my friends, Ferhat Çeviker, Muhammet Duran, Gökhan Şimşek and Kate Austermiller who gave me encouragement and support during my research. I would like to express my gratitude to my mother Nezahat Çelik, my father Sedat Çelik, and my sister Nazlıcan Çelik also to thank Beijing Institute of Technology which give me chance to make this research.

Abstract

Computer vision is very important and necessary science for the medical field. Generally, computer vision intends to help the medicine staff to decide for any diagnosis. There are many diagnosis systems and techniques with computer vision have been developed numerous diseases of organs. Some of these systems are interactive which means manual, semi-automatic or full-automatic. Especially medical imaging techniques have been found such as Magnetic Resonance and Computed Tomography which used to diagnosis any diseases. MR or CT images help to understand problems of patients by doctors. In order to increase the helping more, there are so many researching papers has been publishing related with the vital organ in the human body such as brain, liver, heart, lungs, etc. This study aims the liver segmentation and visualization in order to give more precise and accurate results to doctors or staffs. Liver cancer is among the most frequently observed types of cancer diseases and many patients die because of liver cancer worldwide in every year. The statics show us how serious the liver diseases. In this study consists of three stages. These are the Rough segmentation, Improved Grow-Cut (IGC) and visualization.

In computer vision, image segmentation is the process which extracts objects from a digital image. The main goal of segmentation subtracts the concerned objects from rest of the image to assists people who care about related objects. Manual segmentation systems generally need expert clinician so that type interactive systems consume time and requiring much effort. Also, clinicians can make the mistake then that mistakes can affect the results. However this automatic liver segmentation method based on thresholding then it can be over segmented or under segmented. To prevent this over segmentation or under-segmentation we used Improved Grow-Cut method. Grow-Cut method is a popular segmentation method but it is an interactive method because of that researchers has proposed an Improved Grow-Cut method. This method generates the labels on the image automatically. Visualization is a technique which creates any visual object. Visualization Toolkit (VTK) is an open-source, freely available software system for 3D computer graphics, image processing, and visualization. In this study, we used the VTK toolkit to create 3-D liver models from segmented Computed Tomography (CT) images for improving the understandability of images.

Keywords: Improved Grow-Cut (IGC); Computed Tomography (CT); Visualization; Visualization Toolkit (VTK)

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1. Introduction

Technological developments have continued day by day and said developments have been playing important roles in the medical field. Every day scientists publish new papers or present new inventions in the medicine field, also they try to develop current systems. These improvements help doctors and medical staff to recognize or detect liver diseases. This thesis study will introduce a liver segmentation and visualization system.

As mentioned as above, nowadays technology and medicine field are growing together so any developments can directly affect the medicine field. For example, recently 3-D printers are the latest miracle of technology. However 3-D printers have already begun being used using in medicine field, particularly dentists can produce a tooth according to a patient's teeth measurements in just a couple minutes. Also, the bone system is quite fit for implementation, even researchers have tried to fix some spinal cord problems using 3-D printer system. Maybe in the future, artificial organs which are created with these methods will save a human life.

When we were thinking about thesis issue, we considered artificial systems without interaction. That's why we decided an automatic liver segmentation consisting of automatic detection and refined segmentation without interaction. There are some manual systems already in use to help for doctors to diagnose. Also, this thesis aims to help doctors to diagnosis. However, this project sheds light on the automatic diagnosis systems. Namely, automatic organ segmentation methods can be used with tumor detection methods so systems can diagnosis diseases without a doctor. These systems are also suitable to integrate with machine learning algorithms. This means diagnosing systems can improve with experience with routine diseases automatically. Also, scientists research automatic treatment systems such as surgery robots. These surgeon robots will diagnosis the diseases and even if it is necessary, they will perform surgery on the patients. In the future this kind of scientific revolutions will happen, machines can follow the process from diagnosing to treatments.

Therefore, this automatic segmentation and visualization methods and systems are quite important for developing medicine. This thesis concerns automatic segmentation and visualization and we fully explain automatic segmentation and visualization. Each chapter aims to give fundamental information about the project and give explanations for these titles.

A summarizing look at the chapters in this thesis:

Chapter 1 contains a brief explanation of the main goals of the projects and research questions and hypothesizes. The liver is an important organ for this project in order to grasp the project clearly we will introduce the liver roughly just like where is the liver placed in the body and what are the main functions of this organ. Also, we are going to introduce some keywords such as CT image, segmentation, so on. The liver is especially an important organ for the project, so we will present the liver and some liver diseases and then later on we will talk about the framework of the project and how we handle these processes.

In Chapter 2, we will see what the segmentation is and why we use it. Then we will talk about related segmentation methods such as active contour, statistic shape model, clustering-based methods, and so on. Moreover, we will introduce the rough segmentation is automatic liver segmentation [1]. This method based on thresholding and that is why we will see what thresholding is.

In Chapter 3, we will present the Grow-Cut method and Improved Grow-Cut method. We will describe the difference of them and we will show stronger features of the Improved Grow-Cut [2] [3]. This chapter will show us why we need refined segmentation for improved results.

In Chapter 4, we will render the liver from the segmented images. We use some visualization toolkit to handle that process so we are going to introduce the VTK toolkit which transforms the images from 2-D to 3-D [4].

In Chapter 5, we are going to shed light on the future of this technologies because science builds with snowball effect and all these technological developments can affect very different fields from the car industry to medicine fields, from sports to food sector. As we mentioned in previous paragraphs, we can meet doctor robots in the future. This robot can handle all process from diagnosing to treatments. Thus, we can reduce human interaction in the medicine fields and we can focus different fields to make them useful for humanity. Particularly, we are inspired by 3-D printers in the medicine fields. 3-D printing was been invented a couple years ago but nowadays these printers can be used to produce dental implants. Maybe this automatic segmentation and visualization methods can a herald of a technological revolution.

1.1 Liver

The human body consists of many vital organs. The liver is one of them which located the upper right region of the abdominal area and right side of the stomach, below the diaphragm and covered by the gall bladder. Estimated weight is 1300 – 1600 grams. The color of the liver is red with brown tone and shape of the liver looks like 3 side pyramid. The livers are protected under the ribs because the liver is an important internal organ. The liver is the biggest and largest organ in the human body. The liver consists of four main parts and the human body provides blood to the liver with two main veins. These are portal vein and hepatic artery. Portal vein contains digested nutrients. Hepatic artery connects the liver to the spleen and pancreas. The arterial blood and un-oxygenated blood pour into the liver simultaneously but they do not mix with each other through the lobes of the liver.

The liver handles vital functions such as removing the toxins from the body, synthesizing protein from amino acids, producing biochemical enzymes for the digestive system. In addition, the liver is a gland. Secretions of the liver are quite important for metabolism with numerous functions in the body. These secretions are stabilizing the glycogen rate in the blood, hormone production, protein synthesis for metabolism and so on.

As can be seen from the above description of the important roles and functions, there are also some problems and diseases that are brought along as well.

These are some of the most common liver diseases:

1.1.1 Cirrhosis

Cirrhosis is a serious liver disease which the liver becomes quite wounded, generally the result of ages of perpetual injury. Alcohol is the most spread reason of cirrhosis. Also hepatitis B or hepatitis C diseases, fatty liver because of over-weight or some diseases which damage the liver or another organ continually such as diabetes. Advanced phases of the cirrhosis can’t be irreversible, then liver transplant can be compulsory for treatment. Early diagnosis improves surviving rate of the cirrhosis [5].

1.1.2 Hemochromatosis

The simplest definition of Hemochromatosis is a disease which happens because of the overload of iron mineral in the human body. Many foods contain iron mineral and iron is a necessary mineral for the body. However, remains of the iron absorption accumulate in the organs such as heart, liver or pancreas and that can affect that organ. That's why Hemochromatosis is cause of the organ failure, cirrhosis, diabetes, even rarely cancer [6].

1.1.3 Hepatitis C

Hepatitis is the general term for inflammation of the liver. Hepatitis C can be caused by a number of factors such as Hepatitis B or C viruses, toxic matters, alcohol, and so on. Hepatitis C virus causes chronical inflammation, lesion on the liver and cirrhosis by over time. Also, infected patients are at the risk of the liver failure, vessel problems and liver cancer and Hepatitis C patients has some problems such as excessive alcohol consumptions, obesity, and diabetes that's mean improve the risk of cirrhosis. In the estimated, 170 million people are infected by Hepatitis C virus. [7].

1.1.4 Hepatitis B

Hepatitis B is one of hepatitis that is caused by the virus which consists of double DNA helix. This virus settles to liver, multiple and demolishes the liver cells. Hepatitis B virus keeps the liver cells and makes those cells inaction. Then the cells which blocked to do their tasks by virus die single by single likewise Hepatitis B is infectious. There are more than 300 million hepatitis B carriers in the world, also Hepatitis B causes over than 500 thousand dying a year [8].

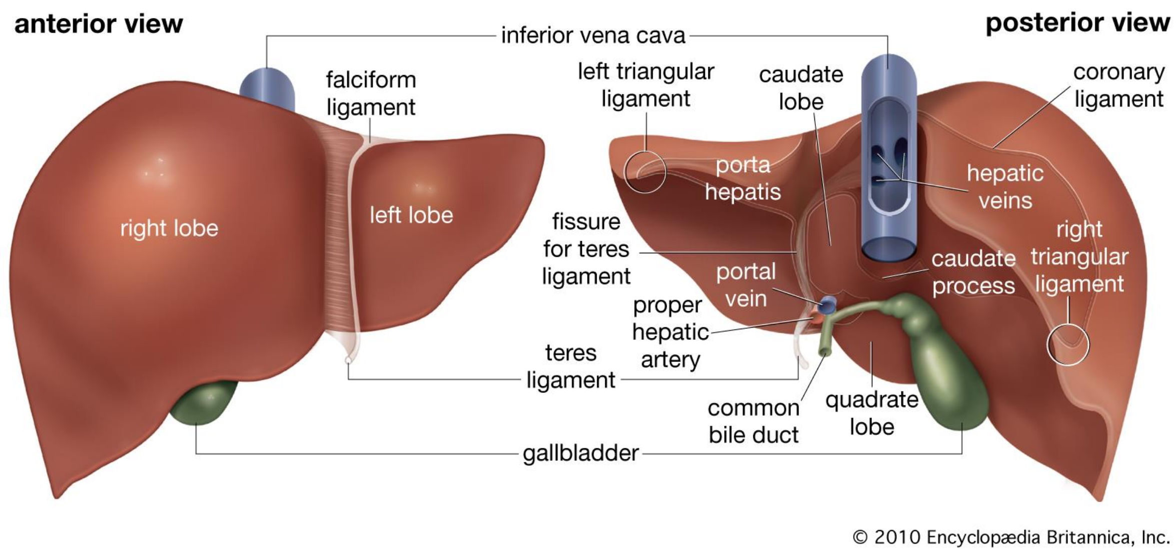


Figure 1.1 Liver and Parts

Doctors need Magnetic Resonance or Computed Tomography images used to diagnosis some liver diseases as can be seen from above. Sometimes that MR and CT images do not give good results. At these time, medicine needs computer science especially computer vision. Because image manipulation such as segmentation or histogram equalization improves the understandability of the serial medical images. This study aims to improve the understandability of images and to give better results to medicine staff.

1.2 Goals of the Project

Liver segmentation and visualization are important steps in computer-aided liver disease diagnosis and surgery planning. The most important step of the liver segmentation is the selection of some image attributes such as thresholding for the accurate segmentation. Automatic segmentation of liver in medical images is a challenging task for accuracy and robustness.

This project includes full automatic liver segmentation combined with Improved Grow-Cut (IGC) method, and visualization by the Visualization Toolkit (VTK) library.

Segmentation aims to make it simple, more meaningful and easier to analyze the image. That means for segmentation there is two important part: one of it is object another one is background. This study has handled segmentation in order to detect the liver organ in CT images. Normally this is a challenging process because staff who use the segmented images need smooth results for diagnosis or detecting anything abnormal on the organs. Segmentation results are significant in the medicine field. Any failure of segmentation results can be the reason of wrong diagnosis. In order to give more precise results, medicine staff used manual segmentation systems but there are some disadvantages for the manual segmentation systems. The manual segmentation systems generally need expert clinicians, and that kind of interactive systems consume time and require much effort of many levels of medical staff. In order to create an automatic system, we use Automatic Liver Segmentation Method [1]. This method is based on histogram thresholding and connected component algorithms and finds the liver on the CT images. However this method is a unreliable method just like all methods based on histogram and to solve that problem we need to calibrate our program. Also, biggest connected components method errors can occur in the segmented result, and in order to prevent these errors we have developed some algorithms.

The Improved Grow-Cut method is the refined segmentation stage of the main segmentation.

The difference of Improved Grow-Cut (IGC) method and typically Grow-Cut method is IGC can generate automatic labelling. [2][3] Improved Grow-Cut makes good use of the continuity of CT series. We use this Improved Grow-Cut in order to make automatic to all systems.

After segmentation, we will have numerous segmented liver images from whole data sets. A standard 2D image has two axes (X, Z), if we combine this 2D images to each other by Visualization Toolkit (VTK), also we will have an extra axis (Y) and these three axis' can generate a 3D template. [4]

Expected results of the project:

In the project each stage give us different result and this results can be the input of the next stages. According to the framework, firstly we need to obtain the result of the automatic segmentation, and in order to obtain that we used the CT image sequence to the system and we waited for the segmented liver images from those CT images. Following the expected result of the first step is shown in Figure 1.2

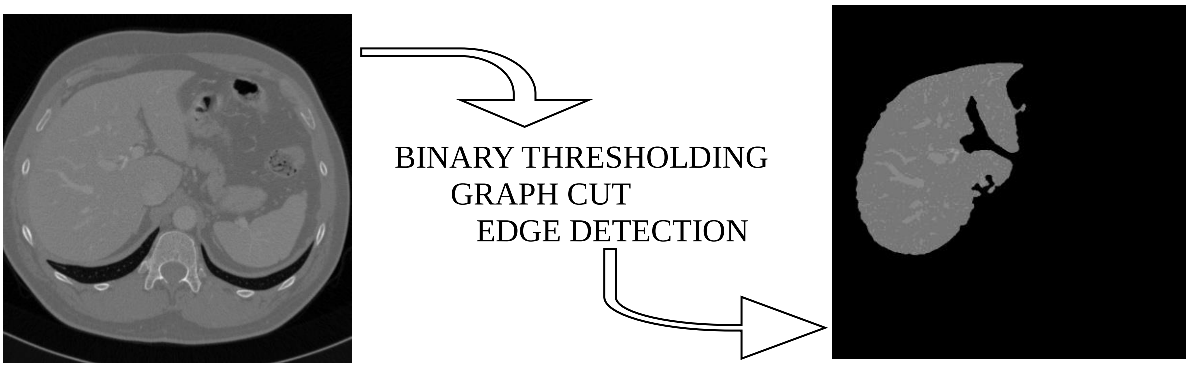
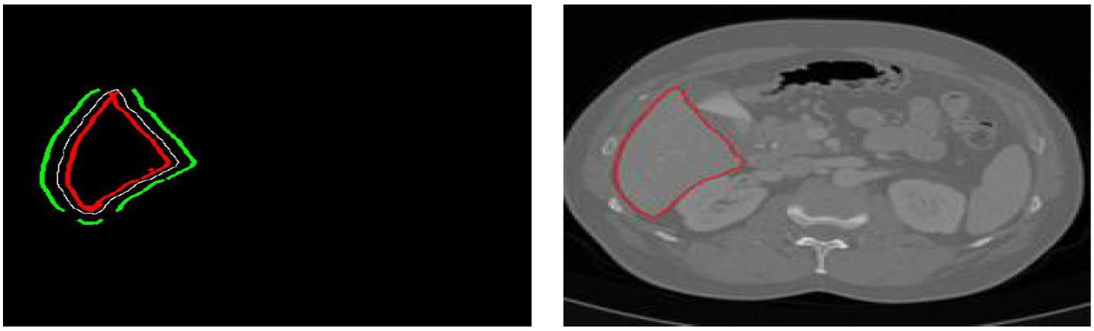


Figure 1.2 Expected Rough Segmentation Result

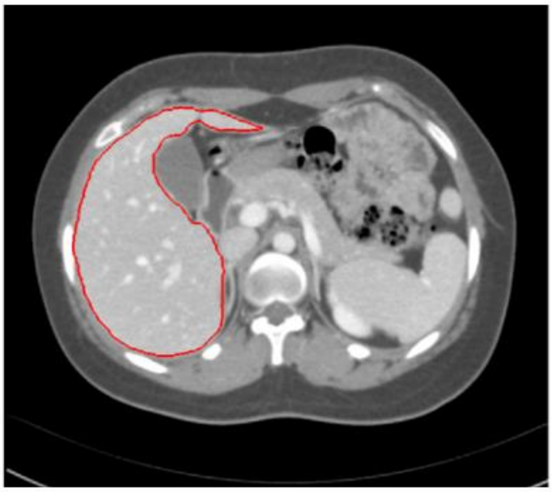
After that processes, we will use these segmented liver image sequence to refine the segmentation. There are so many methods to handle this process but those methods are either manual or semi-automatic that is why we use to Improved Grow-Cut method for refined segmentation. Expected result of Improved Grow-Cut method is in Figure 1.3

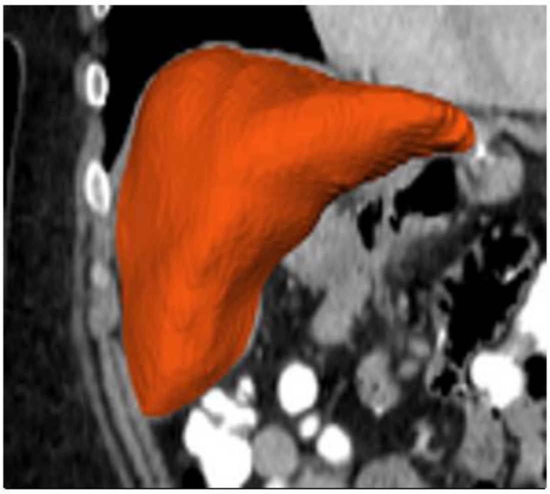


(a) (b)

Figure 1.3 (a) Expected Refined Segmentation Seeds and (b) Result

The last process is the visualization of the segmented image sequence. This process is handled with the VTK toolkit. According to that toolkit, we will convert to the 3-D model from segmented image sequence. An image already consists of a x-axis and z-axis, but for visualization we also need to the y-axis and that image sequence will provide us with the y-axis. The result of the visualization is following in Figure 1.4





(a) (b)

Figure 1.4 (a) Expected Rough Segmentation Result (b) Expected Visualization Result

1.3 Related Work

Segmentation is widely using method in several fields as we mentioned previosly, so many reseachers proposed different segmentation methods we will talk about all these methods in the next chapter with details. Now we are talking about some methods and their lackness aspect for segmentation. Although traditional region growing methods are good segmentation method, they are interactive methods. That is why improved region growing method has been proposed. This method chooses label points by Quasi-Monte Carlo method. However the contour is not so smooth. Statistical Shap Model is also using method for liver segmentation but before the process we need to establish a prior liver shape for segmentation and we need to spend so much time for the process also each model is not avaible for various test subjects so we have to establish a special shape model for every single patient. Some fuzzy c-means clustering methods are proposed for automatic segmentation but this method can be reason of some under segmentation problems. One of clustering based method is SKFCM (Spatial Kernel-based Fuzzy C-means). This method used to segment some tumor lesions succesfully. However SKFCM method is also a manual method.

There is some segmentation and visualization toolkits using in the medicine fields. The most known and famous toolkits are MITK, MeVisLab, MIPAV, and so on. These toolkits has been developed to help end users as doctor also all these toolkits are free and open source applications. Let us break down these toolkits:

1.3.1 MITK

MITK [11] acronym of Medical Imaging Interaction Toolkit which created by a collaboration of German Cancer Research Center and Mannheim University. MITK provides manual segmentation with different methods and generates 3D volume reconstruction.

Pros:

1. Open-source and free segmentation and visualization framework
2. Works on different organs and bone structure

Cons:

1. Interactive toolkit so needs an expert to use
2. Sometimes can be reason of over or under-segmentation

1.3.2 MeVisLab

MeVisLab presents a modular image processing framework and particularly concerns with medical imaging. MeVisLab has been developed and released by MeVis Medical Solutions AG. MeVisLab can offer segmentation and visualization for clinical service staff but in additional there are several clinical prototype are including surgery planning, cardiovascular analysis, so on. [12]

Following the advantages or disadvantages of MeVisLab

Pros:

1. Includes different prototypes such as dynamic image analysis, surgery planning, so on.
2. Powered by strong third party libs and languages just like Qt, Python, OpenGL

Cons:

1. Interactive toolkit
2. Complex interface

1.3.3 MIPAV

MIPAV application is also the acronym of Medical Image Processing, Analysis, and Visualization which analyzes and visualizes medical images. MIPAV offers easily data share via the internet interface so this is the one of strongest attributes of it. [13]

Pros:

1. Allows different imaging techniques such as CT, MRI, PET, and microscopy
2. 3-D volume rendering is quite good
3. Suitable to script code and to add methods

Cons:

1. Interactive toolkit

These prior toolkits used to assist doctor in diagnosing and treatment, also all these applications are open source so many freelance developers try to add new and original attributes to these toolkits.

1.4 Research Question and Hypotesis

1.4.1 Research Question:

1. Is this project useful for diagnosing and treatments from CT images?

   This automatic segmentation and rendering method aims to assist doctors to diagnosis liver diseases and to plan surgery before the operation.

2. Can we use automatic segmentation methods without interaction techniques instead of manual segmentation methods?

   In this project, we used only automatic methods. Even we have added some features to make the project full automatic. For instance generally, we need to choose manually over-segmented image for refined segmentation, we solved this problem checking total pixel numbers of the each CT slice. We assessed a threshold value and if any roughly segmented slice has less or more pixel number than the previous slice we send these slices for refined segmentation.

3. Will images be more useful if segmented liver image use with visualization methods?

   3-D visualization provides us to render the liver from segmented CT images and to use transparency to see both of inside and surface of 3-D liver model. So this is quite significant to diagnosis lesions inside of the liver.

1.4.2 Research Hypothesis:

Visualization of segmented liver improves the understandability of the medical images and data. This project will help doctors for diagnosis and surgery planning.

1.5 General Diagram Flow of the Project

Automatic Liver segmentation project consists of three stages. They are rough segmentation with automatic liver detection, refined segmentation with Improved Grow-Cut Method and Visualization with some toolkit. The first stage is automatic liver detection which detects liver part on the abdominal CT images. This stage is called rough segmentation which is based on histogram threshold method. The output of automatic liver detection is the input of Improved Grow-Cut Method. That means the output of the automatic liver segmentation can be over segmented or under segmented. In order to overcome that kind of problems, we used refined segmentation. This stage improves the accuracy of the detection. And last part of the project is Visualization improves the intelligibility of the detected liver from CT images. Therefore, this project would be significant for medical area. All this project has a quite basic interface. After that processes, we obtain 3–D liver model for a product. The general framework of the project is shown in Figure 1.5

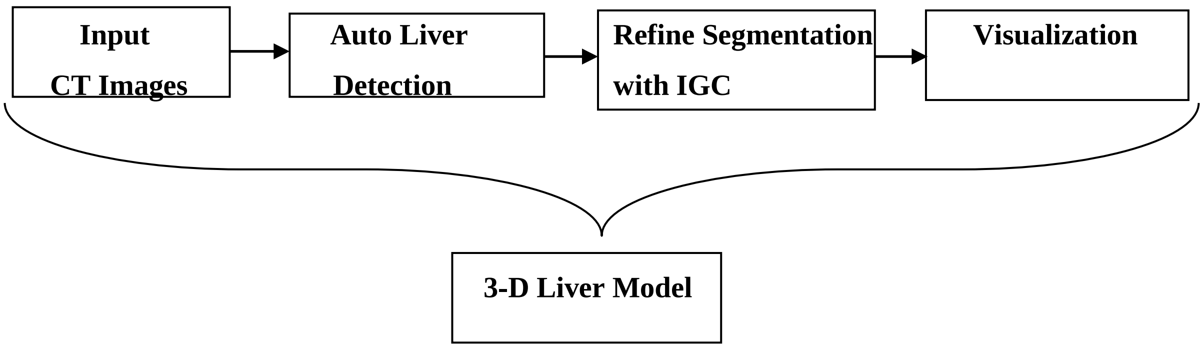


Figure 1.5 The General Structure of the Project

The framework of the project as seen as above includes three main stages. Input of the project is CT images and output is 3-D liver model which is product of the project. We used CT images for this project, because CT images are mostly preferred medical imaging method for diagnosing and treatment systems. CT images which we used in the project is shown in Figure 1.6

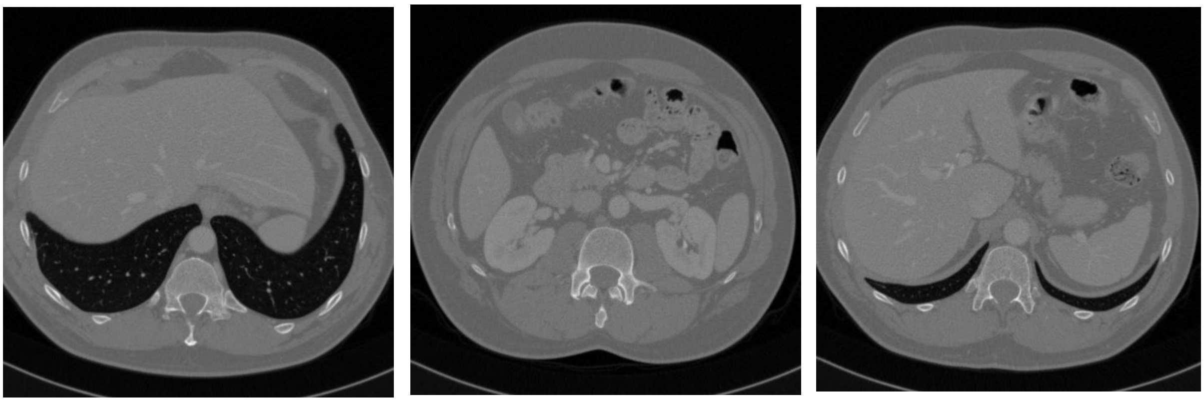


Figure 1.6 Abdominal Computed Tomography Images

As can be seen of above, different slices of the computed tomography are displayed. CT images are the input of our project which has high signal/noise ratio and good resolution. This is why CT images are often preferred by medicine staff. CT image provides accurate anatomical information about the visualized structures. These medical imaging techniques and the advances in the digital image processing techniques motivate the researching which aims to develop more precise computerized methods for the automatic abdominal organ analysis and 3-D volume visualization. [9] [10]

2. Rough Automatic Segmentation

In this chapter, we are going to talk about segmentation with details. Why do we need to segment something? This part focuses on that issue. Segmentation isolates some concerned objects from the background. In video security, for example, the camera mostly looks out on the same boring background, which really isn't of interest. What is of interest is when people or vehicles enter the scene, or when something is left in the scene that wasn't there before. We want to isolate those events and to be able to ignore the endless hours when nothing is changing [14].

In this project we use two segmentation methods; one of them is automatic segmentation based on histogram and the other one is Improved Grow-Cut. First, one represents rough segmentation and the second one represents refined segmentation. Actually, rough segmentation works on so many images to segment but sometimes the results of the rough segmentation can be over-segmented or under-segmented in order to solve this problem we use refined segmentation with Improved Grow-Cut. In this chapter, we just focus segmentation term and we try to explain and find out it with details.

2.1 Segmentation and Methods

As described as above basic description of the segmentation is to separate concerned object or objects from rest of images. We used to segmentation according to image density, color histogram, and so on. After this extracted region can use directly or it needs some manipulation and processes.

Segmentation is used to so many fields in the world from sports to medicine, from security to entertainment sector.

These are some fields where to use the segmentation:

1. Medicine Field
    1.1 Diagnosis any pathologies such as cancer cells
    1.2 Check organ volumes
    1.3 Surgical operations preparation
2. Security
    2.1 Face detection or recognition
    2.2 Recognize some individual properties such as fingerprint

2.3 Some military or government application

3. Others

 3.1 Detection of the farm or jungle area

 3.2 Smartphone applications for entertainment

 3.3 3-D visualization systems

For example, there is a term in soccer which is called offside. This rule is when a player passes the ball to a teammate, his teammate's any body part is between of the last player of opponent and goalkeeper that is called offside. Researchers have published numerous papers related computer vision about this event. In order to figure out this event with computer vision, those papers generally include segmentation methods. According to rule, firstly the researchers need to segment the football ball, the players who touch the ball last time, who is the opponent, who is a teammate of the player who passed him or her. And after that segmentation process if the player who is trying to catch the through ball by teammate place is appropriate or not when the player who pass him or her. The researchers decide it is offside or not. [15]

Let's consolidate the segmentation with a different example. For example, technology develope day by day and maybe next a couple years later we do not need a driver to drive any car. There are many researching with related this subject. According to this researching, the scientists has already invented the car which can drive itself. Cars use different techniques to find the way such as ultrasonic, artificially intelligent, and so on. However one of the widespread ways is roadway detection and the scientist use some segmentation methods to separate the roadway from rest of the objects. [16]

As seen as examples, segmentation is a very useful method in any field. In this project, we will use the segmentation to assist the doctor for diagnosis some liver diseases.

There are so many different ways use to segment the objects from rest of the image. The very spread way is called Gestalt rules [17]. Actually, Gestalt is a psychologic term. It was born in the early 20th century. According to Gestalt, human tend to compose the big picture that called "unified whole" also Gestalt emphasizes the perception.

Some of these principles are:

1. Similarity

Similarity is the similarity of objects to each other. People perceive them as a pattern.

2. Continuation

   Continuation occurs when the eye is compelled to continue through a line which connects two objects to each others.

3. Closure

Sometimes, some objects can be incomplete in the image but automatically we see these objects are completed. Thus, these objects are completed by closure principle. People perceive the whole without any missing information.

4. Proximity

When different elements are placed close to each other or clustered together, people perceive them as a group.

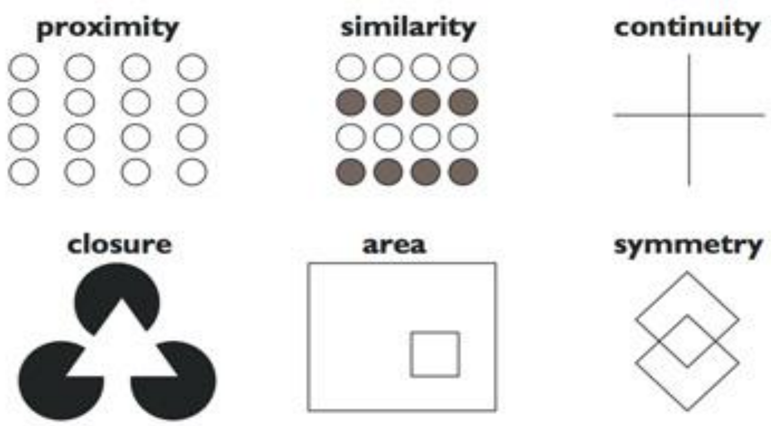


Figure 2.1Factors of Gestalt Rules

Segmentation separates the objects form each other as we said before, also segmentation has criteria such as every method. This criterion is I image is separated by S parts. [18]

1. $\cup Si = S$ => Partition covers the whole image.
2. $Si \cap Sj = \emptyset$, $i \neq j$ => No regions intersect.
3. $\forall Si$, $P(Si) = true$ => Homogeneity predicate is satisfied by each region.
4. $P(Si \cup Sj) = false$, $i \neq j$, Si adjacent Sj => Union of adjacent regions does not satisfy it.

Any segmentation method has to be suitable to this criteria. Otherwise, segmentation method will be a failure.

Digital image segmentation is the manipulation or operation to extract
significant object from the image with using connected pixels:

1. Regions => images consists of all regions.
2. Linear structures => connected linear structs such as lines

3. Shapes => different geometric shapes such as circles

Several algorithms and methods have been proposed for improving the segmentation quality. Each method of segmentation tries to solve a specific or common issues about the related subject. For instance, the method is using for product barcode reading in markets. There are many techniques and methods on the segmentation methods. The mostly using methods are:

1. Thresholding
2. Histogram based
3. Clustering
4. Edge Detection
5. Region Growing

We used all these methods directly and indirectly. For example, we used thresholding methods based on Histogram and some clustering method for automatic liver detection stage. Edge detection is a part of Improved Grow-Cut method and also Improved Grow-Cut method based on Region Growing. As seen as all these methods which are shown in above are related to the project. That is why we are going to break down all these methods single by single.

2.1.1 Thresholding based on Histogram Methods

Thresholding method is one of the mostly using and the simplest method which based on one or two thresholding values. Normally binary images more fit for thresholding methods because RGB images consist of at least 3 channels or some of the images (RGBa) contain extra one more channel which is called alfa channel and this process can be harder for these 3 channels RGB images for every channel need at least one thresholding value.

The last decade, Thresholding method widely using in the medical field such as detecting organ from CT images. However, thresholding method is not so reliable to work singular. That means it can be the reason of bad segmentation for example in a medical image; spleen, liver or another tissue can be similar color range and if we execute the thresholding method directly we can not obtain necessary region for use because of the similar color range problem. As seen in Figure 2.3, different color range gives different results on the same image to us. These results have pointed that thresholding method needs to evolve. Therefore, computer vision scientists have been developed many methods to use with thresholding such as clustering, fuzzy logic even this extra methods have been expanded that fields or have been combined each others for meet the expectations, for example, Otsu Method [19] which is clustering based threshold method without interaction. After these phenomenon methods, automatic thresholding has been used more variety fields. In Figure 2.2 we are seeing the original image and different thresholded images.

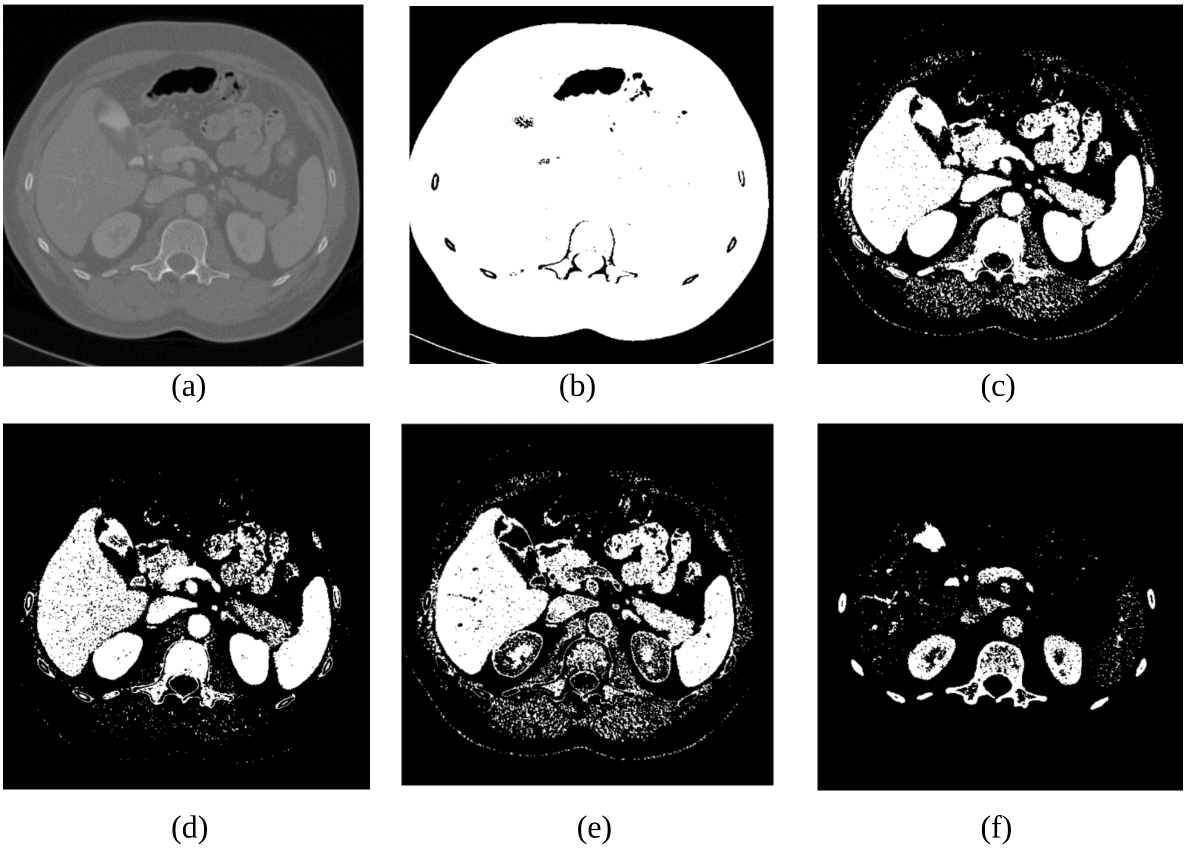


Figure 2.2 (a) Original Image (b) %90 Thresholding Value Result (c) %70 Thresholding Value Result (d) %60 Thresholding Value Result (e) %50 Thresholding Value Result (f) %30 Thresholding Value Result

New methods proposed to improve the thresholding performance including fuzzy based non-linear threshold. Also, any threshold methods can be processed without interactive, that's mean before segmentation user do not need to provide any prior information. These methods have begun to propose in 1960's.

Automatic Threshold Segmentation Method:

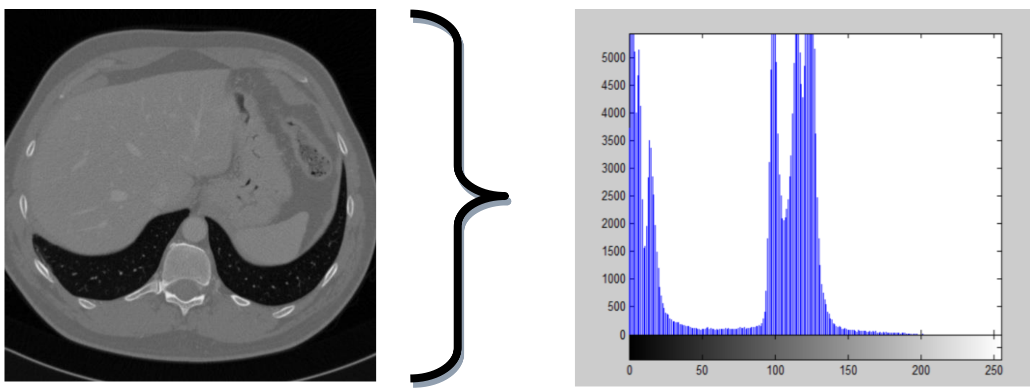
In automatic segmentation, the thresholds are assessed without interaction. This selection based on different ways such as the shape of the concerned object or density of the color, and so on. There are some methods for automatic segmentation, this method such as clustering, gaussian distributions, and so on combine any methods with thresholding [19] [20].

Histogram based methods:

An image histogram is the distribution of the color tones in the image. For example, generally size of any channel in a digital image is 8 bits and corresponds to grayscale image consists of 255 tones that minimum tone level is 0 represents dark color as black, maximum tone level is 255 represent light color as white and the colors are between these values from dark gray up to light gray. Histogram-based methods widely used to segment digital images. That is why the systems or user can access directly related color gap of pixels. The histogram shows us tonnes of images and generally similar part of any object has similar color tones. For example in a grayscale, a medical image such as tomography, the liver ordinarily consists of colors between 110-130 tonnes of color. This values can ben changeable depends on of conditions just like brightness and if we take that interval out, we can obtain the liver but generally, there are so many tissues and organs in the body with similar color tones because of this issue, this method always does not give accurate results. However, sometimes just some manipulation processes such as dilation, erosion or smoothing can be enough to obtain the concerned object. Indeed, the success rate is quite low to use only that algorithm in complex projects.

A histogram consists of peaks and valleys and this is kind of measurement of the density or color in the image. Histogram seeking method has been presented to refine the histogram. Histogram seeking severs the image into small clusters then this mini clusters can be divided into smaller clusters and this process retains until no more clusters are formed.

Histogram based systems can be used in the video segmentations. These approaches are very adapted in multiple frames. That’s why histogram based segmentation methods are useful for video segmentation including object tracking, detection or recognition. . In Figure 2.3, there are an original image and histogram table of the image are given.



(a) (b)

Figure 2.3 (a) Grayscale Image (b) Histogram of the Image

As seen as above digital image histogram is significant for the sight of the image. Histogram algorithms generally based on detection of peaks and valleys and sometimes this task can be challenging to identify significant merges. We can decide that with just looking to image histogram about image; underexposed, well exposed or overexposed. Depends on to conditions image can be underexposed and overexposed. Generally, this is not intended state. Histogram equalization is a method to solve that problem. The tones of color are more density in an interval in underexposed or overexposed image. Histogram equalization distributes that color density and assigns that tone suitable color interval. This process provides a well-exposed image clearly. Also, These are some Histogram based methods are multi-thresholding [21] , two-dimension (2-D) or three dimensions (3-D) segmentation [22] and so on.

Edge detection methods are based on thresholding based and it is quite a useful method and using in image processing widespread. The main idea is each object has some different properties in the image, for example, a cup on the table. The transition from the pixels of the table to pixels of the cup usually does not be smooth because cup and table have different color properties in the image than when the transition from the table pixel to cup pixel is a sharp transition. Edge detection often uses a sharpness of the adjacent pixels. These methods are useful for the disconnected edge of the vague contours. Some segmentation methods also handle the edges which acquired by edge detection methods. Lindeberg and Li proposed an integrated method which extracts the edges into different shapes segments for object recognition. [23]

2.1.2 Clustering Methods

Clustering is the partitioning of a data into coherent regions. Clustering methods widely used to categorize the coherent data set in different fields such as data processing with big data, image processing, and so on. In data processing, clustering methods try to find data which has similar properties in the data stack. Then this data are labeled by that clustering method roughly so stack looks regular. Indeed, clustering tries to find out the correlation between data or regions. Also in image processing, for instance; pixels which have similar color are categorized by clustering then some special regions become suitable to segmentation.

When we call clustering methods the first two methods which come to mind are the K-means algorithm and Mean-Shift algorithm. We are going to break down these methods.

2.1.2.1 K-Means Algoritm

K-means method is an iterative method which used to divide an image into similar properties as color or texture. Firstly user or system decide how many cluster will use in the project. K represents this cluster number. For example in single channel image segmentation, If we assign any value (such as 4) for K that means in the gray scale we gonna divide four different values. Then algorithm picks any four points in image randomly and these points are called cluster center. In next step, other pixels are going to be a member any of these clusters according to their distance to cluster center. Afterward the new cluster centers are assessed by average of the cluster members. This iteration will continue until the cluster centers do not change. The k-mean method obtains K partitions on the image. [24]

These are the steps of K-means method:

1. Choose K cluster centers in image randomly
2. Find the closest cluster center for each pixel and assign them the cluster
3. Calculate the average of the clusters and assess the new cluster center
4. Iteratively repeat step 2 and 3 until cluster center is fixed.

Literally K-means algorithm consists of these four steps. After the last iteration, we obtain the clustered digital image. In this clustered image shows us the similar regions in same color tones after that we can extract the concerned region from rest of the image easily.

2.1.2.2 Mean-Shift Algoritm

The Mean-shift algorithm is an iterative and non-parametric clustering method which proposed by Fukunaga and Hostetler. [25] Mean shift try to find out local maximum and modes in feature space. Assume a circle centered at image and radius is a kernel of it. The center of the circle tent to move density, this moving is called mean shift vector. Mean shift vector points to density, and each iterative changes the center of circle step by step. This iteration continues until the center of the circle also become the center of the density.

The main steps of Mean Shift Algorithm:

1. Create an imagined circle with r radius on image
2. Calculate the average density of modes in feature space
3. The center of the circle shifts the new point which averages of the density
4. This shifting retains until the center does not change in the iterations.

The advantage of the mean shift segmentation is that we can find the details such as color, slope or texture without prior information then this advantage opens the door for the automatic segmentation method with mean shift method.

2.1.3 Region Growing Method

Region growing method usually starts with one pixel in the potential region and the grows to neighbors of this pixel. Starter pixel or seeds can be assigned to the digital image by manual or automatical. The first criteria of the region growing are similarity of the pixels. This similarity has been defined between starter pixel and cluster pixels in order to grow with rely upcoming. This is the main theme of Region Growing. However the results of this method are influenced by noise and that incident affects performance and reliability of the method.

2.1.3.1 Statistical Region Merging (SRM)

Statistical Region Merging (SRM) method [26] has been proposed in order to prevent that noise problem. Generally statistic test of SRM decides that each pixel will be a member of any region. That mean region is a population which has similar statistics. This statistic test checks the neighbor pixels to be suitable for any region. SRM using 4 connectedness pixel model with edges weighted by the absolute value of the density difference. Therefore, SRM sorts those edges in a particular priority line and assess to merge the related regions belonging to the edge pixels with that statistical method.

2.1.3.2 Seeded Region Method (SRG)

A different region growing method is the seeded region growing method (SRG). [27] According to this method initially, determined seeds marks the concerned objects for segmentation. Later another undetermined pixels assign to regions with the difference between current pixel value and average of the related region. Then this seeds check their adjacent using a measure of similarity in order to grow and figure out the end of the concerned objects on the image. SRG retains until all undetermined pixels be a member of any region. The disadvantage of the SRG is if any seed is marked on the noise that can create some problem or reduce the performance of the system.

2.1.3.3 Region Growing Method based on Pixel Intensities

This method presented by Haralick and Shapiro. We need to calculate the average and distribution of the region and density of related pixel for the statistic test. This statistic test evaluates the pixel whether belong the related region. [28]

The steps of the method based on pixel intensities;

1. Statistic test is small enough so related pixels be member of the region
2. Re-calculate average and distribution of the region
3. If the statistic test is not small enough that pixel is rejected by region and handles for any region.

2.1.3.4 Split-Merge Method

The split-merge method is also known as quadtree segmentation. That method contains two stages. One of these is the split stage and another one is merge stage just like the name of segmentation. Roughly definition of split stage checks the image part and if finds some regions are not homogeneous, divide the image for four sub-part. Then merge stage tries to connect that dived regions if they are homogeneous to each others. [29]

That method firstly uses the whole picture then if does not find any correlation each others split that whole image to four equal regions then we obtain so many different regions with this recursive method later we check correlations of that sub-divided regions and merge those regions. This method continues until there is not any region to split or merge.

Split merge method also can use with some different methods and the method has been developed. For instance, bimodality detection approach [30] is one of them. This method has been proposed to overcome some lacking in the adaptability of traditional split-merge methods.

That method contents an automatic thresholding technique based on bimodality detection with using image semantics. This method overcomes some segmentation problems based on histogram thresholding because the split merge method always uses any histogram thresholding method. The split-merge algorithm gives quite good results for segmentation. That’s why the method is useful and popular among other segmentation methods.

There are several region growing methods already have been proposed. These all methods try to solve segmentation problems. Region Growing methods are rooted methods for image processing and several methods using in the industry. In addition, these method have developed day by day. Also in this project, improved grow cut method based on region growing to be applied.

2.1.4 Watershed Method

Recently, watershed segmentation [31] is a popular method. Especially, in the medical field, there is many methods has been proposed related with the watershed method. This method particularly used to detect tumor on organs such as the brain. Generally, watershed segmentation is a topographic surface which contains gradient. Three types points are handled in the watershed. These are local minimums, catchment basins, and watershed lines. In the method as assumes water flows from watershed line to minimums though catchment basins. These points are shown in the Figure 2.4

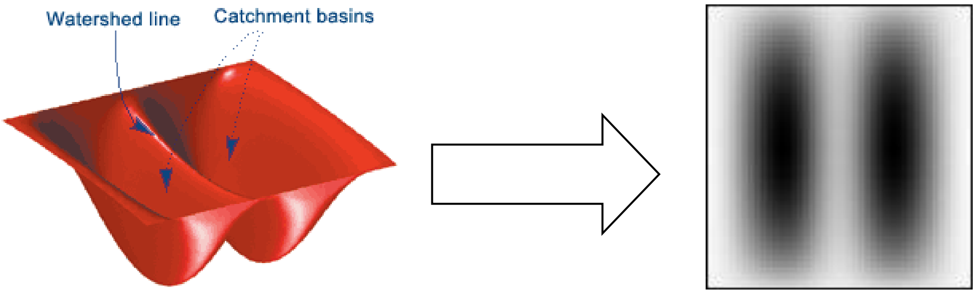


Figure 2.4 Watershed Lined and Catchment Basins on Real Image

Roughly, original image transform to grayscale image because watershed segmentation works on grayscale image. Gradient magnitude is assessed with sharpness or smoothness transition of the image. This gradient magnitude is kind of edge detection. Then the watershed algorithm is applied to the image. This method shows watershed line and catchment basins then immersion is applied on that image. Immersion application used to flood, after flooding the edges and the watershed line has been eroded. This erosion process is necessary to figure out the ends of the objects. The last form of the image which is handled by watershed segmentation points the edge of the objects. [32]

These are the steps of watershed method:

1. If original image is 3 or 4 channels, transform to grayscale image
2. Extract topography with Gradient Approach
3. Apply Watershed algorithm and figure out the local minimums, lines, and catchment basis
4. Find edges of the image

According to these steps, we can handle watershed segmentation. Also, different gradient approaches such as morphological, Euclidean or the topological can give different results. The watershed model can compare with Active contour method. However, these two methods are suggested to work together. Both of methods have some advantages and disadvantages to compare with each other but when using together the segmentation performance is improved.

2.1.5 Active Contour Model

Active Contour is also called Snake Method. This method minimizes the energies of the image. These are energy is some features of the image such as line, edge and termination functionals. The energy of these features is divided by integral operations. This process is more different than edge detection methods. The method creates continuous and curved lines and that’s why the method is called snakes. Internal forces (physical attributes such as smoothness) and external forces (data of the image) are applied on the object and find out the boundaries of the objects. Active contour model has been proposed to overcome visional issues such as the line or edge detection, object tracking. [33]

2.2 Automatic Liver Detection and Rough Segmentation

As we mentioned previous chapters, recently liver segmentation is quite important for diagnosing of liver and also diagnosing techniques based on segmentation is spreading day by day. Also, new segmentation methods have been published. That points us to the significance of the organ segmentation from medical imaging.

Manual liver detection methods need an expert for interaction. Because these methods need to crop or mark by the user so this interaction can bring some issues with along. For example, any carelessness and negligence can be the reason of the wrong segmentation and this process can go until wrong treatment to patients than the patient even die upon these hazardous treatments. Segmentation methods generally used to assist doctor but automatic segmentations also can give shape the future just like mentioned in the introduction chapter. Automatic liver detection is a challenging process because liver and other adjacent organs are quite close each other by the way that tissues and organs also have similar color range with liver in the CT images. [34] To overcome these issues we are going to use some characteristic attributes of the liver. The liver is placed in the abdomen, between stomach, intestines and thorax. Also, liver is located on the left side of the CT image. The liver is the largest organ in the entire human body, we will point out later that this characteristic is very important for the next algorithms which detect the liver.

The framework of the rough segmentation is shown in Figure 2.5:

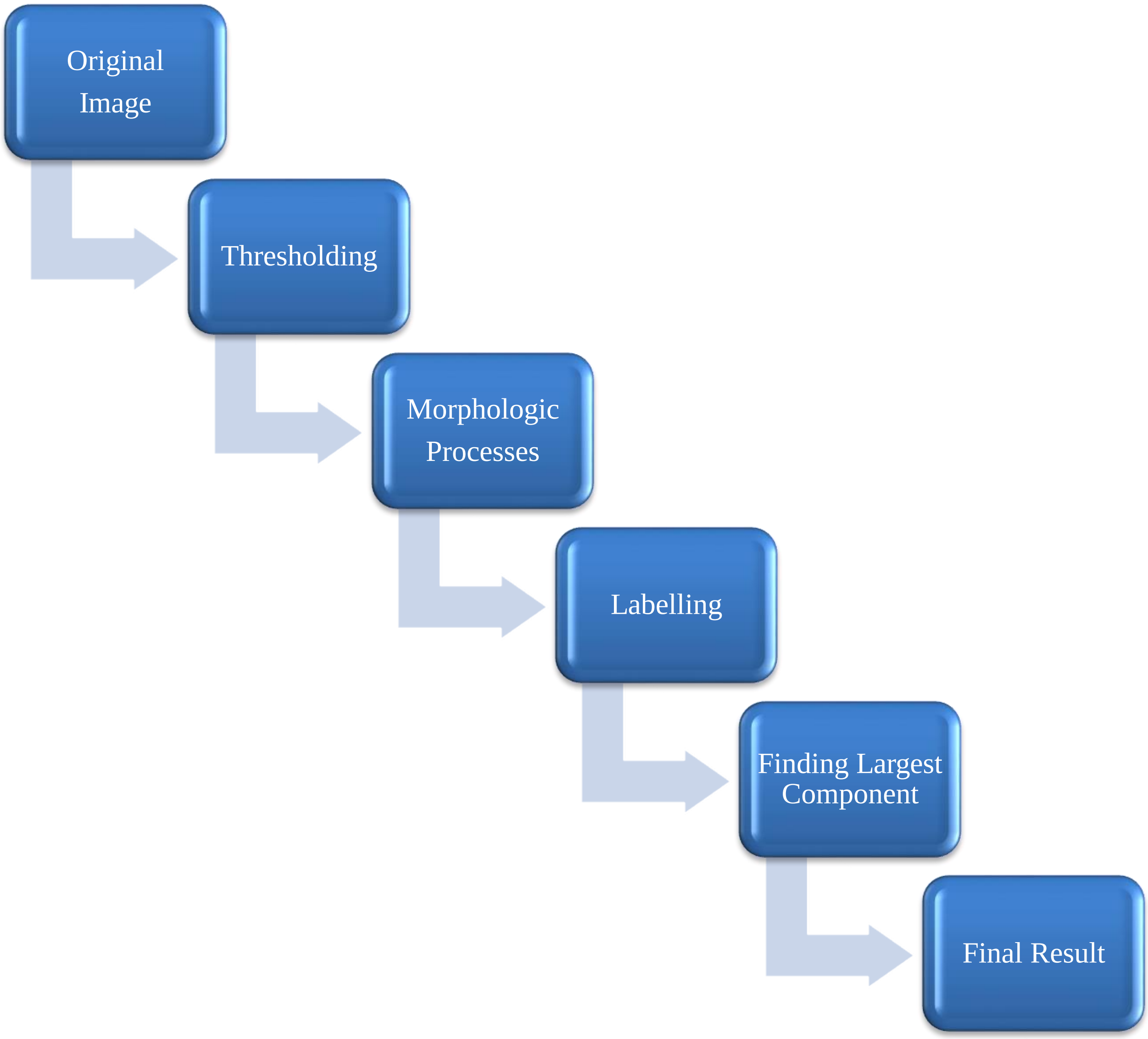
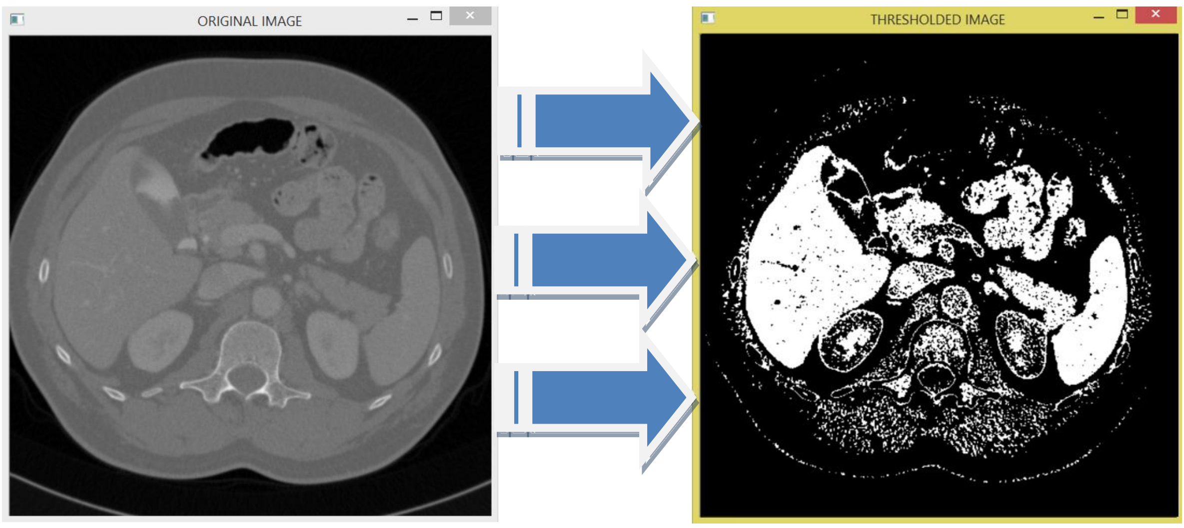


Figure 2.5 Framework of the Rough Segmentation

These all stages of the framework handle the rough segmentation. In this sequential process, the output of any stage is an input of next one. The original image is the first input to all system and processes, then we threshold assessed liver gray scale interval. After this thresholding process, we obtain liver and similar tissues even organs so the liver can be connected with some part which does not belong liver. Morphologic processes such as erosion and dilation used to smooth for the thresholded image. Then we start to label pixel according to their adjacent thus we find out largest connected component thus, indirectly we also obtain the liver. After obtaining the largest component, afterward, we use some matrix operation to segment the liver from rest of the labeled image. As seen rough segmentation consists of 5 stages. Literally these stages are thresholding, morphologic processes for smoothing and preparing for labeling stage. Afterward labeling stage, we obtained labeled connected component to picking the liver up among these connected components, we need to use that information that liver is the largest organ in the abdomen. Thus, if we pick the largest connected component in the labeled image that gives us the liver. Then we can use some masking operations on the image therefore, we have already segmented the liver from all image. When we are breaking down the stages, we will see that masking stage with details. However, just this information is enough that when we assess the liver in the image, we will create a blank image which contents same sizes and all pixels are zeros than we assign ones to places which are marked as largest components. The labeled image and masked image will multiply with each other than we directly obtain the largest component liver in the image. Now let us break down these stages.

2.2.1 Thresholding based on Histogram Interval

Original CT images are the input of the project as we mentioned. Thresholding stage is the first method in this project. An original image enters this method and thresholding gives us a binary image. [35] Previously experiences point us that liver is placed between 115 and 135 intervals in the histogram of this grayscale CT images. Thresholding marks all these points which placed between 115 and 135 in the histogram of CT image as 1 and rest of the image pixels are marked by 0 and we obtain a binary image which contents just 1 and 0. After these process, we have obtained a thresholded image as seen as Figure 2.6



(a) (b)

Figure 2.6 (a) Original CT Image (b) Image is applied by Thresholding Method

This images figure out the output of the thresholding. As seen as, we applied to the threshold with the liver interval but output image consists of so different many components even we can see spleen along liver because these components and organs have got approximately similar color range in the gray scale image. Then only thresholding methods are not enough, so generally, we should use thresholding with different methods to improve the segmentation performance.

Also, there are some problems if we use narrower thresholding interval we cannot find some parts which belong to the liver. Otherwise, if we use the larger interval to the threshold, we can find some unrelated components. So that can be the reason of so much effort to eliminate these redundant components.

We need to use different techniques to obtain liver as we said, that's why we will use labeling and find largest connected components algorithms. These methods will eliminate the redundant pixels and noise and we will obtain pure liver object in the CT image. After we obtain the thresholded image, next step is some morphologic processes.

2.2.2 Morphologic Processes

Thresholding methods generally do not obtain the desired results as we mentioned in the thresholding part. So we will use labeling method, but before using labeling we need to handle some morphological process to make the CT images smooth.

Firstly, we are going to erode the thresholded image to remove some noise pixels and make some components erode and after that process, we can handle a purer binary image. Erosion process is quite important for image manipulation, particularly eliminate redundant components and noise and works with checking adjacent of the pixels. Assume any 3x3 cluster in the image, center of this cluster checks the neighbor pixel with 4-connected or 8-connected methods and according to their values, the center pixel mark itself by zero or one. This thresholded image without morphologic process is shown in Figure 2.7 (a).

After the erosion process, we can see some unwanted holes or deformations on the concerned object as seen in Figure 2.7 (b).

These deformations even can affect segmentation performance to reduce these deformations and to fill the unwanted holes, we will use flooding method to help us. Flooding method used to marks all connected pixels by the same color just like assume the image is colored with three colors as gray, black and white. Objects are colored by white color represent thresholded parts and also concerned objects are among these part. All pixels which are irrelevant with objects and compose the background are colored by gray. Thus, we can access directly holes in the objects because after coloration process with white and gray, also we have been obtained some black pixels and components in the objects. So these black components are unwanted holes and we need to combine them with white objects. As seen as this process, flooding method is useful to access and modify these unwanted holes in the object.

We can assess components which are surrounded by white color with flooding method and we can mark these points with black so we have been filled these holes. Flooding method result is shown in Figure 2.7 (c).

We have already filled holes and remove redundant pixels from the image but we need to make smoother the image. So we also need a filtering method. Median filter [36] is a filtering method which used to make smooth to the image. The median filter is using in medicine field widely.

Median filter works with blocks such as 3x3, 5x5, so on then chooses the center of these block and sorts these pixels according to their values and finally pick up the median value of the sorted sequence and the center pixel of the block is marked by this median value. Median filter aims to remove extreme pixel values, the median filter is quite available for salt and pepper noise removal. By the way, if we increase the size of template window just like 7x7 or 10x10 we obtain smoother image but simultaneously we will reduce the quality and resolution of the image. We need to choose template window as seen this trade-off mechanism but generally 3x3 template windows used to median filter because this is kind of optimum trade-off rate. Particularly in the medicine field, details and sharpness of the image are quite significant, but also noise is a big problem to solve these problems 3x3 and 5x5 template windows are using widely in the CT images.

Formulation of the median filter is following:

$$\mathrm{g}\,(\mathrm{x},\mathrm{y}) = \mathrm{Median}\left(f_s\,(\mathrm{x},\mathrm{y})\right) \qquad (1-1)$$

Where S represents the blocks (such as 3x3, 5x5), $f_s(x; y)$ shows pixel values of the block, Median ($f_s(x; y)$) is the middle value of the all pixels in the block.

Subsequently, after the median filter, we have already finished all morphologic processes and we have been obtained a smooth image without unwanted holes. These segmented images are the output of the morphologic process and input of the labeling method. The output of the morphologic process is shown in Figure 2.7 (d).

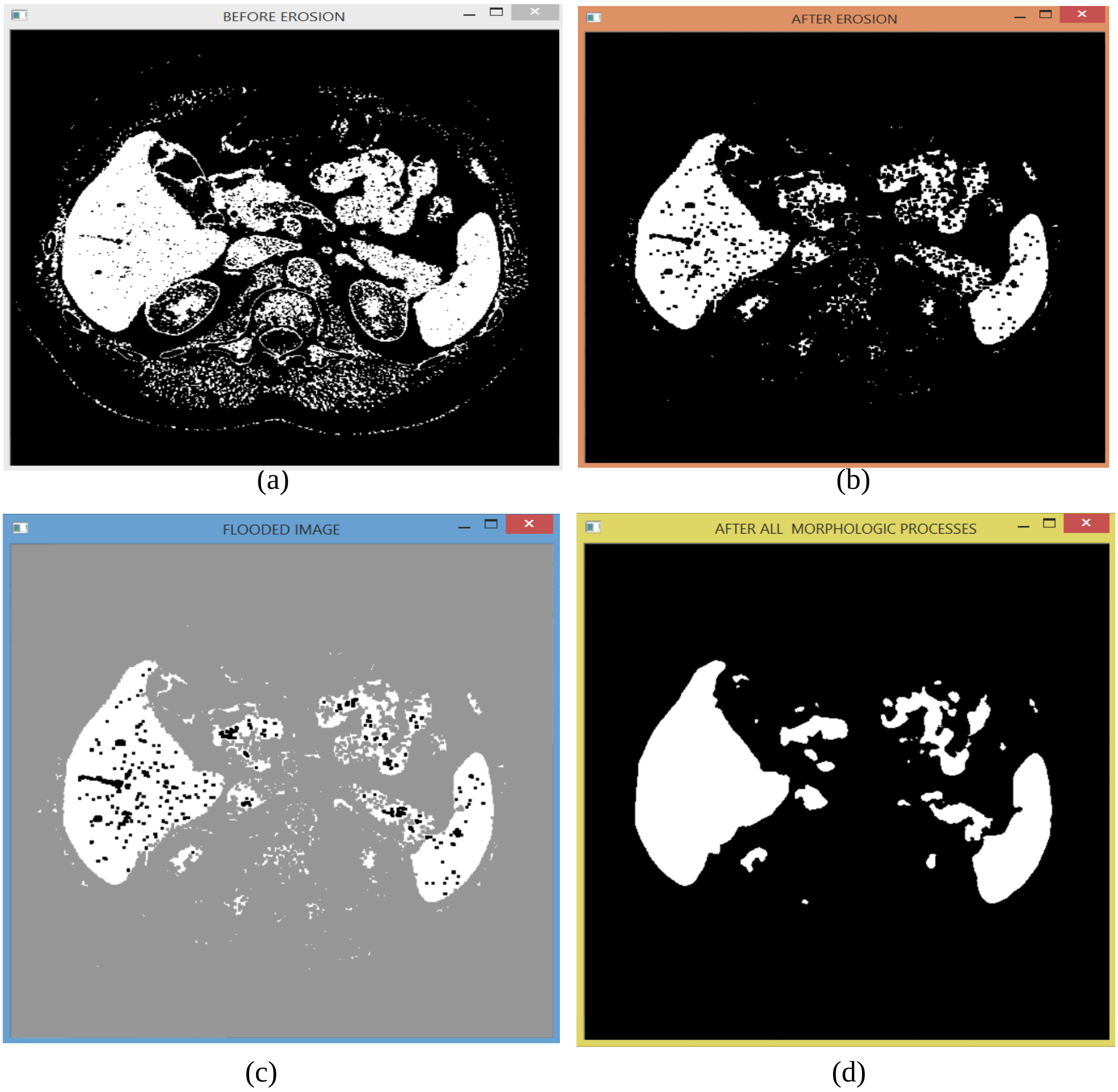


Figure 2.7 (a) Result of the Thresholding, (b) Elimination of Redundant Components using Erosion Process, (c) Marked Image with Flooding Method, (d) After all Morphologic Processes

All these morphologic processes, the CT image is modified for labeling method to find largest connected component. Here we continue with labeling method in the next step.

2.2.3 Labelling and Largest Connected Components Method

Morphologic processes provide a smooth CT image without unwanted holes, components, and less noise. Now we are going to use Labelling Connected Components method [37]. Labelling Connected Component algorithm is not segmentation but it is a part of the segmentation. Generally, this method is using with interaction. Firstly, we need to figure out binary ones in the image and then we need to label them and their adjacent according to their neighboring system. The widely using neighboring systems are Moore neighborhood with 8-connectivity and von Neumann neighborhood with 4-connected pixels. According to these neighborhoods, we need to pick a center pixel and if there is some binary one pixels around it, these adjacent pixels and center pixel are marked by the same label and label values are count up for any found new binary one pixels. Iterations check the neighbors of each pixel thus if pixels has different binary one adjacent pixels that their labeled connected components grow step by step. After the last assigned labeled pixels, we have obtained a labeled connected components as seen as Figure 2.8

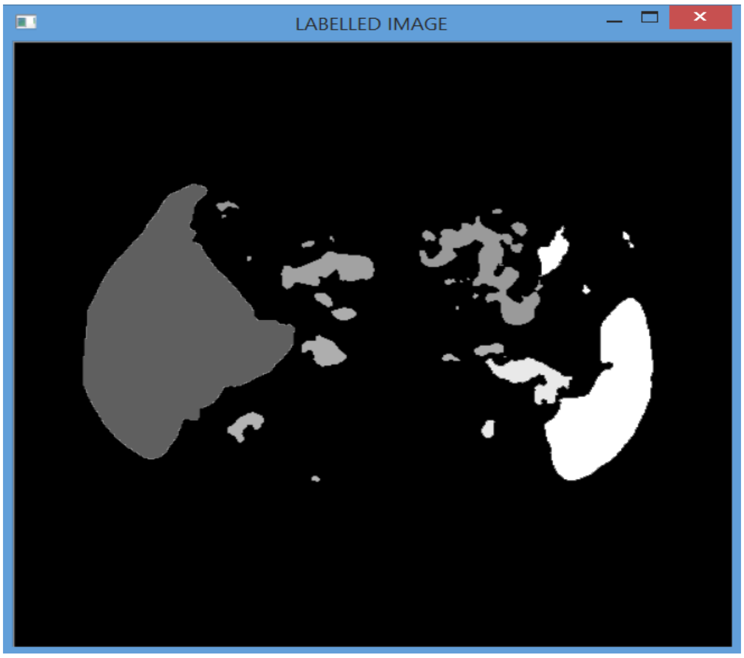


Figure 2.8 Labelled Connected Components

In the programming phase, there is some libraries and default functions are developed to label connected components. So that's why Labelling stage is based on flooding method in the because when we catch any pixel which is marked by one, we also figure out the connection of the pixel so flooding method is so useful for this process. Any discrete component will be marked by labels with this method from the smallest components to the largest component.

We already have obtained labeled components, now we need to figure out the largest connected component. We need to find out the maximum used the label in the image that will give us the biggest component in the image, and generally, the biggest image is liver in the abdomen CT images. Then if we can extract the biggest labeled part from the rest of the all labeled parts that we can find the liver. So we need to figure out the histogram of the image then we can also use some kind of thresholding method to extract the largest part of the image.

Steps of the Labelled Connected Components are:

1. Mark connected components with the same label
2. Figure out histogram of the image
3. Find out the largest component using histogram

These three steps on the above are the basis of the Labelled Connected Components method. Histogram of the labeled image shows us the maximum used the label and this label also represent the liver. The histogram of the labeled connected components image gives us the result as seen as Figure 2.9

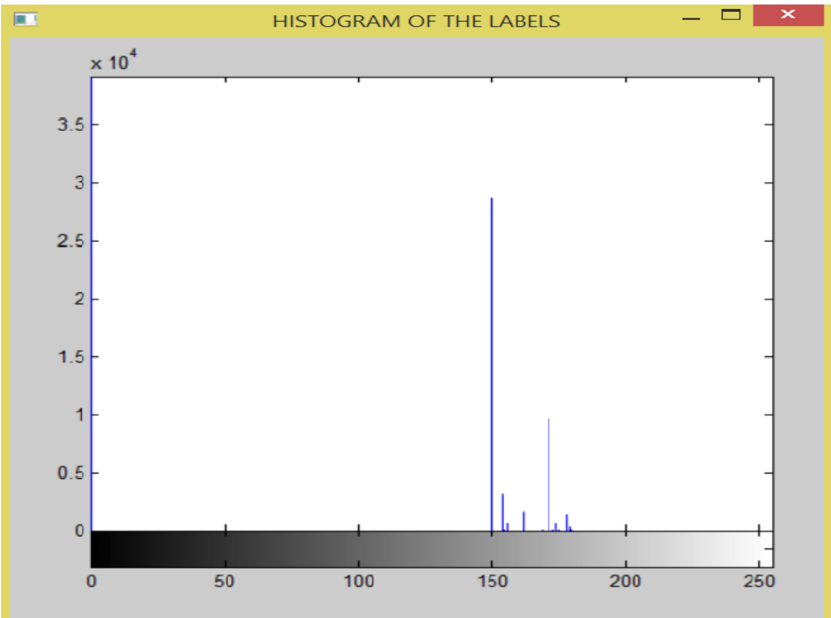


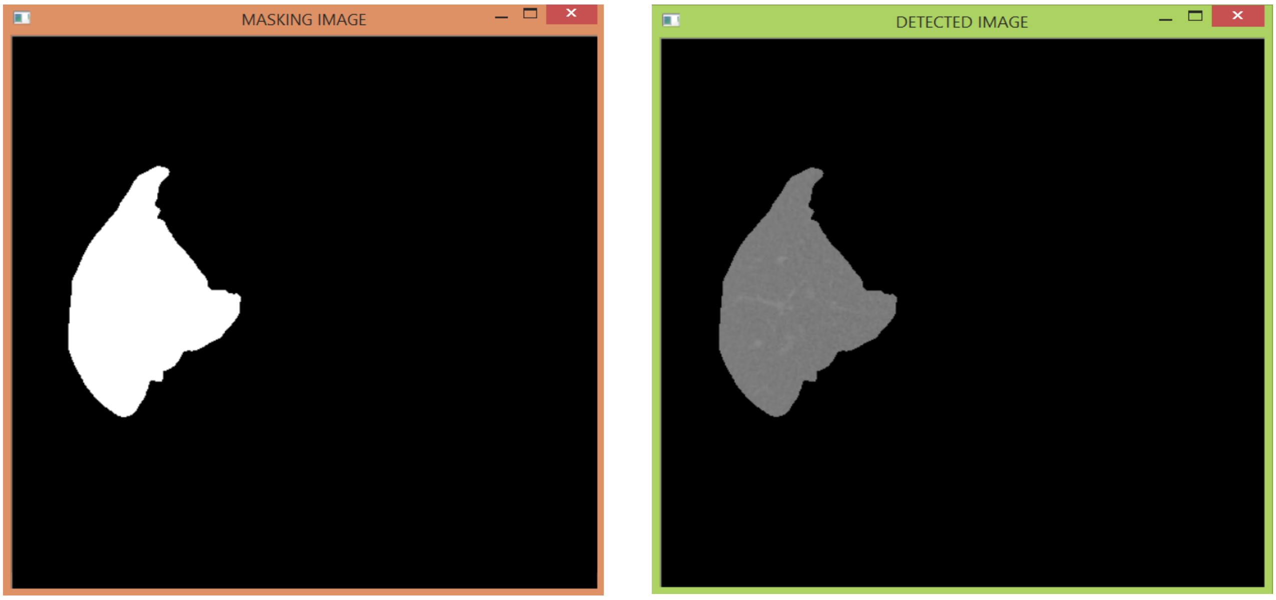
Figure 2.9 Histogram of the Labelled Image

For example in the project, Zero represents the black as seen as a histogram, the background of the image is black and that's why black is the most used color tone in the grayscale as seen as the image consists of around 3.5x104 pixels are labeled by zero. Black is mostly used tone in all CT images so we need to figure out second most used a ton to figure out largest connected component. The second most used color tone is 150 on 255 according to the histogram. Thus, if we pick these pixels which are labeled by 150 that we can figure out the liver. Around thirty thousand pixels are labeled by 150 tonnes on 255 so all pixels which belong to the liver are marked by same color tone. Each CT image has a specific label of the largest connected. So we need to calculate these specific color tones single by single to figure out the liver in the image.

We have already detected the liver in CT image then we need to segment it from the image. The last stage of the rough segmentation is masking to obtain the liver. We are going to explain the masking techniques and applications in the next stage.

2.2.4 Obtained Final Result

We have already known the label of the liver. So we need to use some masking techniques to segment the liver from the image. Generally, this masking technique can work to check each pixel whether available for criteria or not. Firstly we need to create a blank binary window is filled with zeros also this window is called masking image and it consists of the same size of the original image. Then the masking algorithm checks each pixel in the labeled image. If the pixel has the value of the pre-known liver label, that the same pixels are marked by binary ones in the masking image after the masking processing we obtain the mask of the liver, the masking image is shown in Figure 2.10 (a). After we have obtained the masked liver we are going to multiply this masked image and the original image by point by point matrix multiply. Each liver pixel multiples by one and other pixels are multiples by zeros. Thus, we have obtained the segmented liver from CT image as seen as Figure 2.10 (b).



(a) (b)

Figure 2.10 (a) The Masked Liver Image, (b) Segmented Liver from CT image

Therefore, we have completed rough segmentation with automatic detection of the project. Some of the outputs can be over-segmented or under-segmented. That's why we need to use Improved Grow-Cut segmentation to refine the result of the rough segmentation. Before we are going to talk about the Refined Segmentation. let us review the what we did in Chapter 2.

2.3 Summary of Chapter 2

In this chapter, we explained why segmentation is important in the computer vision, the main basis of the segmentation, and we exemplified different job fields and sectors how to use segmentation. Later we surveyed the popular segmentation methods such as Thresholding, Watershed, Clustering, and so on. Generally, we try to introduce segmentation, segmentation fields, and variety segmentation methods.

Rough segmentation with Automatic liver detection was our second significant title in the chapter. Firstly, we used CT images (Fig. 2.11 (a)) for the thresholding segmentation (Fig. 2.11 (b)) with liver gray scale color interval. So we have started the project. After thresholding segmentation, straight away we manipulated the thresholded image with some morphologic processes (Fig. 2.11 (c)) (Fig. 2.11 (d)). We removed some redundant components and noise from the image.

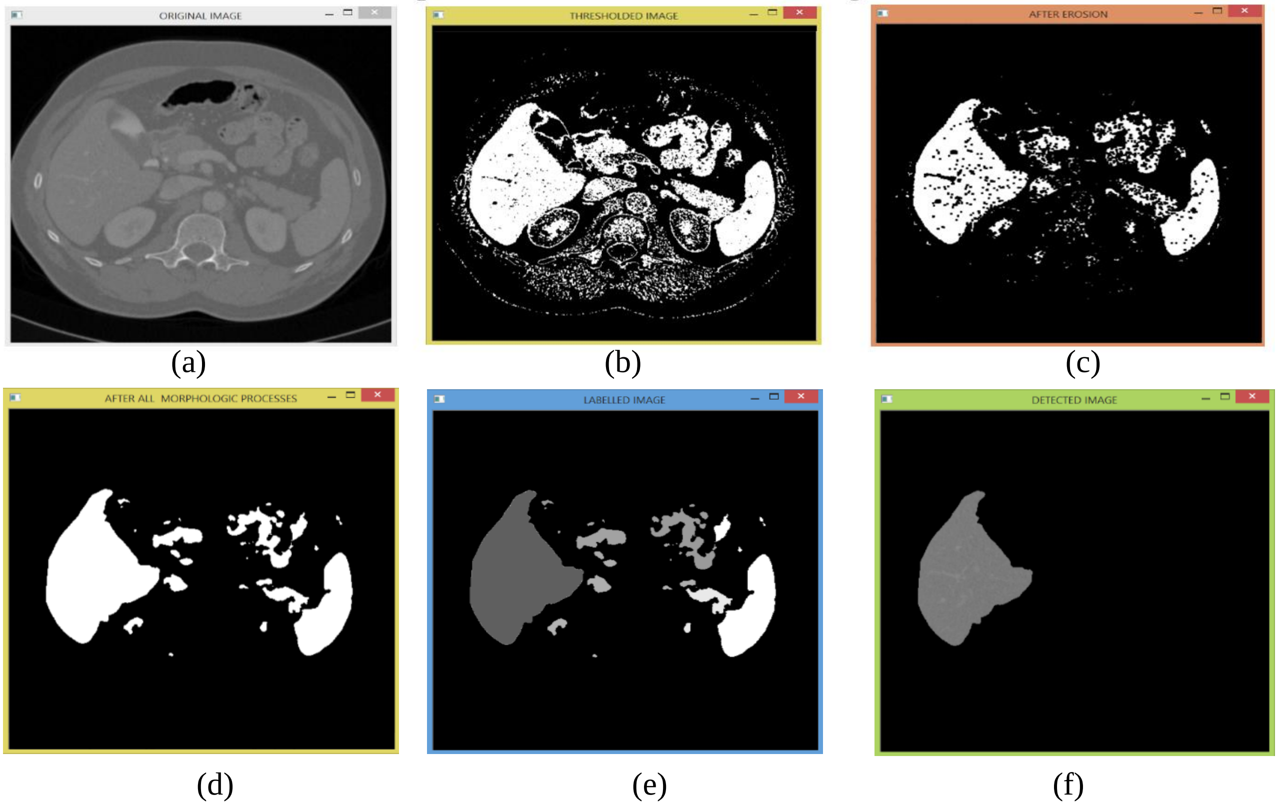


Figure 2.11 (a) Original image, (b) Thresholded Image, (c) Eroded Image, (d) Obtained Image After Morphologic Processes, (e) Labeled Image, (f) Result of Rough Segmentation

After these components are marked by labels (e), thus we access the liver on the image and we segmented this liver region from rest of the image using masking method. Therefore, we obtained the liver (f) from CT image using automatic detection of the rough segmentation.

3. Refined Segmentation

We have already done the rough segmentation with automatic liver detection as we mentioned in Chapter 2. Now we are going to talk about how to refine the rough segmentation. After we obtain the segmented liver from the CT images, some of them can be over-segmented or under-segmented. The accuracy of the segmentation can be reduced and that can be the reason of the problem because of the over-segmented or under-segmented CT images. Refined segmentation is quite important to solve these problems.

Grow-Cut Method is a suitable method for the Refined Segmentation to re-segment the results of the rough segmentation and overcome the over and under segmentations. Grow-Cut method has been proposed by Konouchine and Vezhnevets in 2005. It is an interactive method, we need to mark the concerned object and background after the marking this points to try to find similar pixels and spread such as bacterias. The Traditional Grow-Cut is based on Cellular Automata [38] as an image model. Usually, Grow-Cut method are marked the image by labels, these labels consist of an object, background and gray region. The object is a concerned region, background irrelevant region and gray region has not marked region yet. Then these pixels which are marked by background or object attack to adjacent pixels which are marked by gray region this process continue until there is no any pixels are marked gray region label. Grow Cut method is a useful method for segmentation, especially it widely used to segment particular region such as bones and organs in the medicine field but some researchers realized some lack about Grow Cut method because it is an interactive method as we mentioned the method need manual marking by a user. However, any interactive methods are not available for this project because one of the first goals of the project is automatic using without any user intervention. When we were checking the literature, we found the method which works as efficiently as Grow-Cut and does not need any interaction. This method is called Improved Grow-Cut (IGC). The one of the good attributes of the IGC is automatic seed label generation. IGC refine the rough segmentation results using with these automatic seed label generation algorithm. Previously, IGC segmentation used to kidney segmentation [39] and liver segmentation [2] with some methods for rough segmentation such as SKFCM [40].

In a nutshell, in the project, we will take advantage of the automatically generated seed labels using IGC after automatic detection and all system components use without manual intervention. Firstly, we are talking about Traditional Grow-Cut method, then we will introduce Improved Grow-Cut method and applications in this chapter.

3.1 Traditional Grow-Cut Method

Traditional Grow-Cut (THC) [3] method is a segmentation method which has been proposed by Vadim Konouchine and Vladimir Vezhnevets. TGC is a segmentation based on Cellular Automata [41][42] so before to find out the Grow-Cut, we need to understand Cellular Automaton. Generally, TGC needs manual marking to start segmentation after marking process we have already obtained three labels, these are the gray region, object, and background. According to their adjacent pixels, background and object pixels attack the pixels which are marked by gray region. This attacking process retains until there are no any gray region labels. The object and background labels multiply in the image even this process is quite similar the relationship between living organism cell and bacteria. Now, we are going to find out Cellular Automaton logically.

Cellular Automaton (CA) is proposed by von Neumann and Ulam in the second quarter of the 20th century. CA is applied several various fields these are theoretical biology, computer theories, physics, chemistry, structure modeling, and so on. Especially, in computer systems CA is using from video games to cryptology, from computer processor to image processing including edge detection and remove noise from the image. [43]

CA contents a regular grid of cells just like the matrix, and each cell store a state such as on and off (This is also the basis of the microprocessor). These grids store in any number of dimensions.

Generally, initial states are assigned when t=0, later t count up one by one and every step cells change their states according to some rules such as mathematical functions, so this process decides the new states of the cells using their current state and their adjacent cells state.

For example, assume a chess board, this chess board represents the cell cluster and each square on the board points any cell. So each cell is assigned by states, these states can be some chess piece like bishop, pawn, rook, so on or can be empty. CA connects the state of the cells in the t time to state of the cells in the t-1 time in the discrete time.

CA is defined as $A = (S; N; \delta)$, where S represents set of non-empty state, N is the neighborhood system. Moore and von Neumann neighborhoods are mostly used systems. Moore is 8 connected, von Neumann is 4 connected neighborhood systems and $\delta : SN \rightarrow S$

defines the state transition rule of cells at time t + 1 based on the states of neighbor cells at time t.

These two neighborhood systems [44] are defined below,

Von Neumann neighborhood is:

$$N\ (p) = \left\{ q\ \in Z^N : \left|\left|p\ - q\right|\right|_1\ := \sum_{i=0}^{n} |p_i\ - q_i| \quad = 1 \right\} \quad (3-1)$$

Moore neighborhood is:

$$N\ (p) = \left\{ q\ \in Z^N : \left|\left|p\ - q\right|\right|_\infty\ := \left| \underbrace{max}_{i=1,n} p_i\ - q_i \right| \quad = 1 \right\} \quad (3-2)$$

Also, each cell is called cell state which defined as Sp = (lp; Θp; Cp), where lp represents concerned cell label, p is the strength of this cell and can be assigned any value between 0 and 1, and Cp is the feature vector which points the segmentation of medical images is density.

A medical image (P) consists of two-dimensional matrix and this medical image, and all of the pixels of the image are called the cell. Each cell is marked by labels such as background, object (foreground) and gray region (undefined). [45]

The initial state each pixel is set to

$$l_P = 0;\ \Theta_P = 0;\ \mathrm{C}_P = I_P \qquad (3-3)$$

Where l_P is the density of the each pixel and initially all of these pixels are marked by zero but according to TGC, all pixels are assigned to one of the labels. TGC is an interactive method as we mentioned so the user needs to mark background and foreground labels in the image, and after marking process system automatically create a marked image which consists of the same size with the original image. This marked image contents three labels, foreground pixels are labeled with l_P=1, background pixels are labeled with l_P=-1, and rest of the pixels in the image are labeled with an initial value is l_P=0. The original strength is Θ_P=1 for foreground and background points. This iterative segmentation until there is no any pixel is marked by l_P=0.

We marked an original image (Figure 3.1 (a)) with foreground and background labels (Figure 3.1 (b)). Then we have obtained strength image(Figure 3.1 (c)) and labeled image (Figure 3.1 (d)) . This is an iterative process and eventually we have obtained the Grow-Cut Result (Figure 3.1 (e)) according to final obtained labeled image.

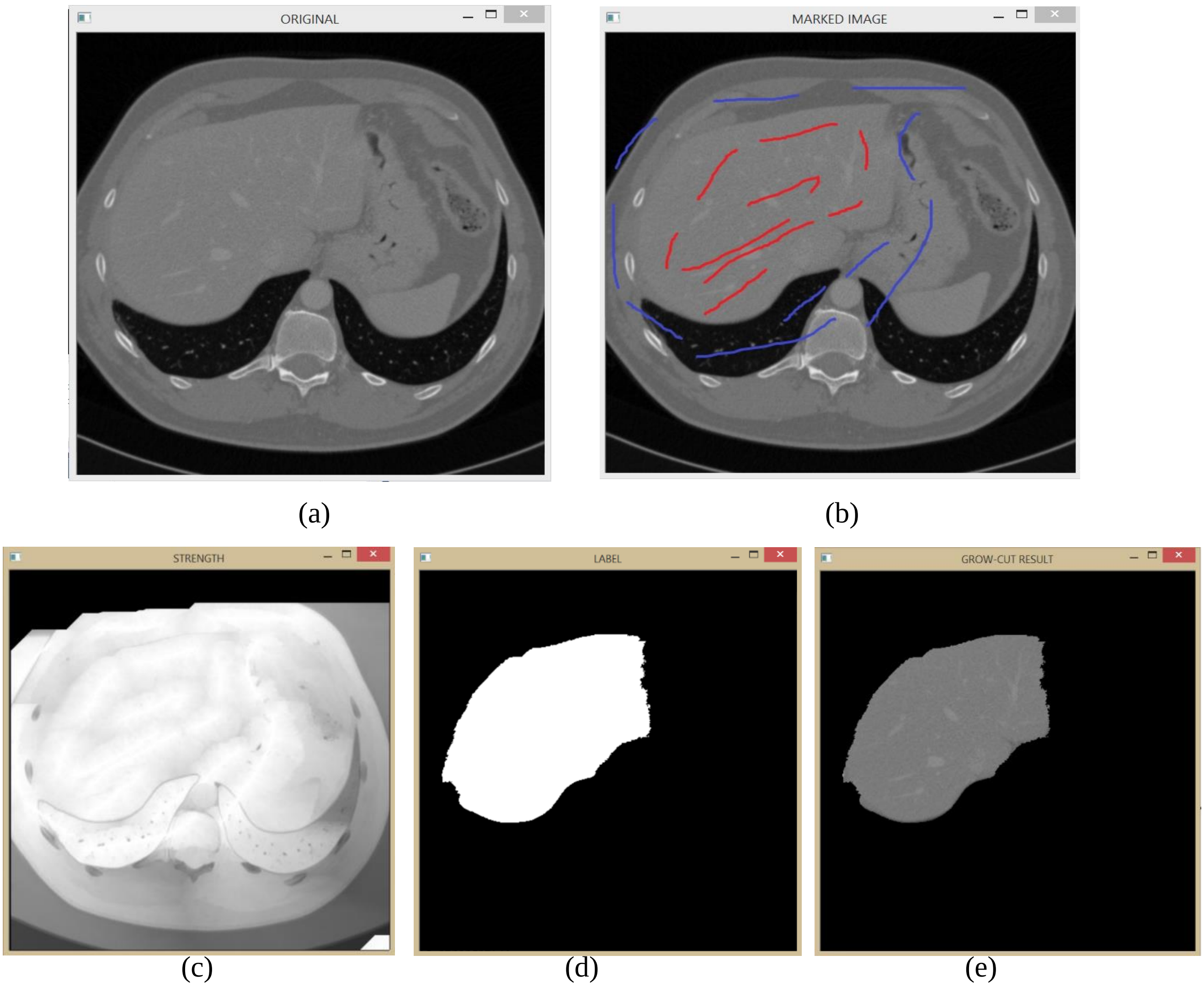


Figure 3.1 (a) Original Image, (b) Marked Image by foreground and background labels, (c) Strength Values Image, (c) Labelled Image, (e) Grow-Cut Result

As seen as above the image is handled by TGC based on CA in Figure 3.1, segmentation results are quite quality. There are no any segmentation problems obviously. We can break down functions of the TGC segmentation.

Following the automata evolution rule:

```
// For each cell
for ∀ p ∈ P
// Copy previous state
l_p^{t+1} = l_p^t;
Θ_p^{t+1} = Θ_p^t;
// neighbors try to attack current cell
    for ∀ q ∈ N(p)
        if g( || C_p − C_q ||_2 ) · Θ_q^t > Θ_p^t
        l_p^{t+1} = l_q^t;
        Θ_p^{t+1} = g( || C_p − C_q ||_2 ) · Θ_q^t
    end if
  end for
end for
```

This pseudo code points out the main basis of the TGC obviously. Firstly, that each cell are assigned the initial values. Then in the next discrete time which is called t, cells copy the previous state at time t-1. The marked pixels by foreground and background try to grow toward their neighbors. This growing effort is defined by strength Θ_q of the foreground and background labeled pixels. $\vec{C}_p - \vec{C}_q$ expression points out the distance feature vectors between labeled cells ($\vec{C}_p$) and undefined cells ($\vec{C}_q$).

$$g(x) = 1 - \frac{x}{\max\ (C)} \qquad (3-4)$$

According to [46], g(x) is a decreasing function and its value is between 0 and 1, x represents current pixel value and max (C) is maximum limit value of any pixel. If the strength of the labeled cells is greater than undefined label's strength, the undefined label, and its strength are changed by the label which attacked the undefined cell. As seen as the labels which have the biggest strength are spread. This process continues until all undefined labels are assigned by foreground and background labels.

The main idea of TGC method is quite similar a biologic metaphor. [46] We can assume these background and foreground labels are a kind of bacteria and these first marked points are the home to bacteria. These bacteria try to spread all image such as different cells in the body and the strongest bacteria conquers neighbor cell and grow step by step.

3.2 Improved Grow-Cut Method

Traditional Grow-Cut is a simple and useful method and results are quite satisfying. However TGC needs manual foreground and background marking for interaction and we do not want any interaction method in this full-automatic system because the user needs to select the labels cautiously otherwise the systems can face with some segmentation problems.

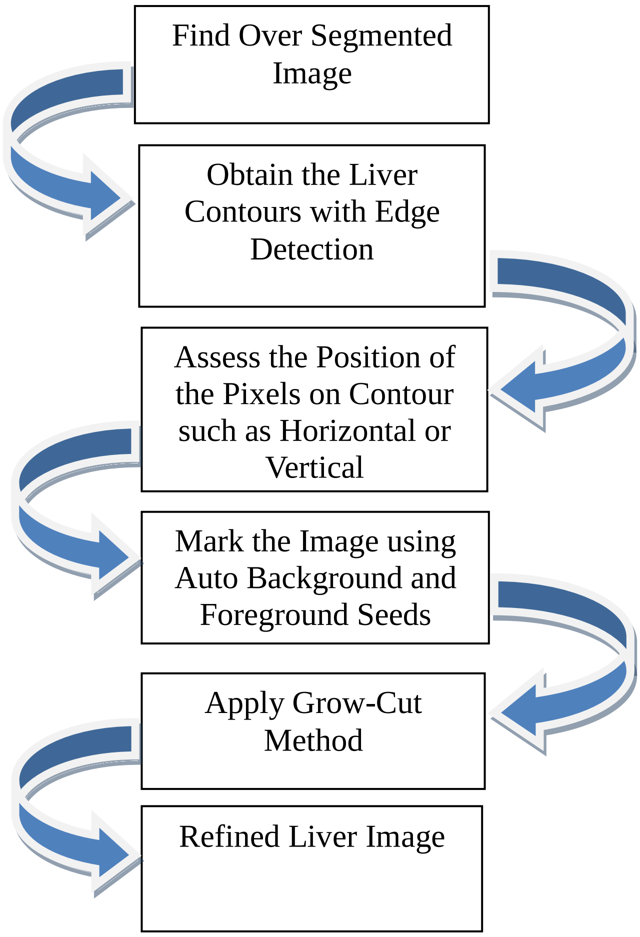


Figure 3.2 Framework of Improved Grow-Cut

Improved Grow-Cut (IGC) method aims to solve these problems based on interaction, and IGC includes the automatic seed label generation algorithm as we mentioned previously. The rough segmentation results are continuous. Also several results of rough segmentation do not need to be refined because these results are already segmented without over-segmentation or under-segmentation. Thus, some results of rough segmentation are used to guide refined segmentation in order to mark the initial labels in the original image. This guide image is called seed template image and needs to meet some basic requirements as shown below:

1. The seed template image does not need refined segmentation
2. The template image has to be consecutive with other images which will needs to be refined

This IGC method directly tries to generate seeds which are marked by foreground and background labels with the template image. Also, IGC detects the liver part in the next slice. When the liver is detected in the image according to ends of the liver will we need to grow the liver window in the image by 5 or 10 pixels and the new window gives us the detected liver in the next slice?

So there is a problem is how will we understand any slice has under or over-segmentation. In order to overcome this problem, we also take advantage of the CT sequence. The occupied liver region increases or decreases in the image slice by so we assess a threshold for the increased or decreased regions. For instance, the liver region in any slice consists of 2000 pixels so the liver region of next slice needs to consists of the interval between 1900 and 2100 pixels otherwise, there is some under segmentation or over-segmentation problems in the next slice. As seen as all system components contents methods based on automatic because the main idea of this project is creating a fully automatic system from detection to visualization and to archive this automation system, we use and produce several automation techniques. Actually, Traditional Grow-Cut method is explained and we will use this Grow-Cut formulation as mentioned before. Now we have already come to “Improved” part of IGC. This “Improved” part adds the automatic adjective to the Grow-Cut method because this label will figure out automatically. We need to detect the edge of the liver then we mark the foreground and background labels according to this edge. So edge detection is the first part of the IGC. Roughly after obtaining the ends of the liver that we need to assess the background and foreground labels. These labels are placed according to some threshold values as we are going to talk about it later. This process continues until all foreground and background labels are marked. IGC consists of four steps generally, these steps are:

1. Get edge points of the liver
2. Calculate altitude difference between two close edges
3. Mark these foreground and background labels according to thresholding
4. Continue Step 2 and 3 until all labels are marked

Now we are going to break down these steps and combine each other, later all these methods are integrated to the whole system.

3.2.1 Edge Detection

Edge detection is a frequently using method which figure out the ends of any objects. Edge detection is also one of segmentation methods. In industrial fields and medicine assisting, various edge detection techniques are used for different processes. Generally edge detection methods focus the sharp color transition between neighbor pixels. The mostly known methods are Canny [47], Prewitt [48] and Sobel [49].

Canny involving Gaussian filtering, intensity gradient of image, edge thinning and double thresholding methods. Canny edge detection is also used to real-time applications in FPGA and DSPs.

Prewitt method calculates horizontal and vertical derivatives approximations with following formulas:

$$G_x \begin{bmatrix} -1 & 0 & +1 \\ -1 & 0 & +1 \\ -1 & 0 & +1 \end{bmatrix} * A \qquad (3-5)$$

$$G_y \begin{bmatrix} -1 & -1 & -1 \\ 0 & 0 & 0 \\ +1 & +1 & +1 \end{bmatrix} * A \qquad (3-6)$$

Where G_x and G_y are derivative approximations, and A represents the image. These G_x and G_y are kind of vectors which direct to right and down so these formulas are given the gradient magnitude and gradient's direction:

$$G = \sqrt{{G_x}^2 + {G_x}^2} \qquad (3-7)$$

$$\theta = \arctan2(G_x, G_y) \qquad (3-8)$$

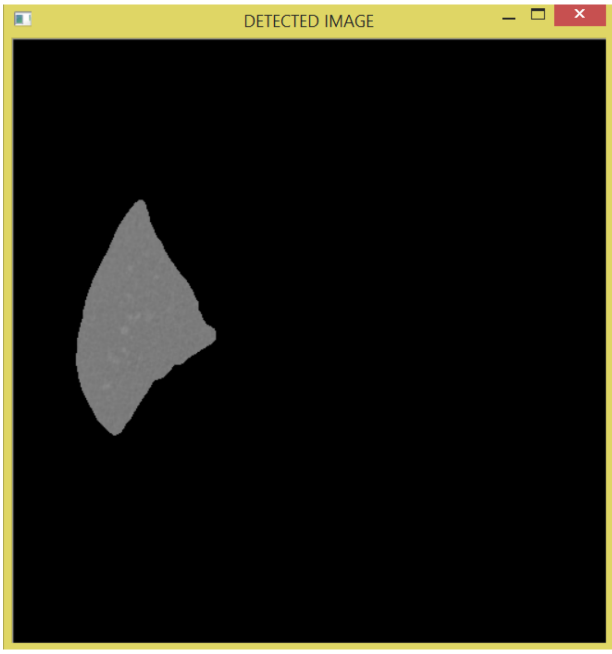
Sobel is also a different edge detection method similar to Prewitt detection. Sobel edge detection is using different derivatives approximations these are:

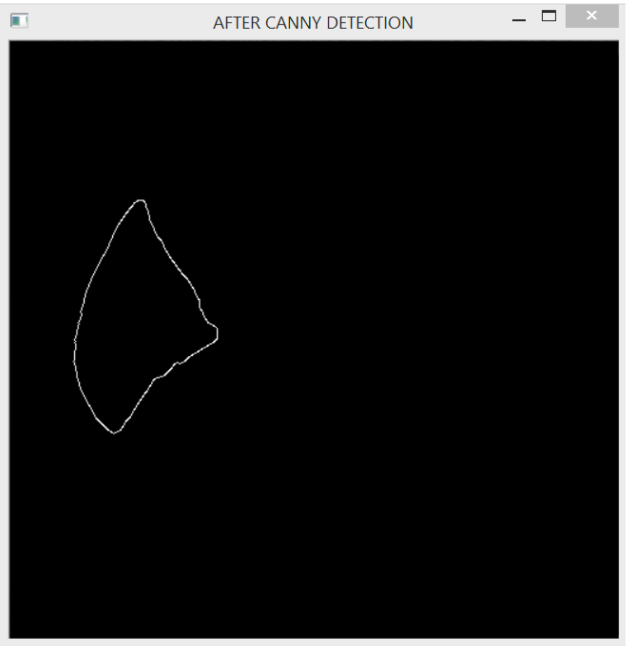
$$G_x \begin{bmatrix} -1 & 0 & +1 \\ -2 & 0 & +2 \\ -1 & 0 & +1 \end{bmatrix} * A \qquad (3-9)$$

$$G_y \begin{bmatrix} -1 & -2 & -1 \\ 0 & 0 & 0 \\ +1 & +2 & +1 \end{bmatrix} * A \qquad (3-10)$$

Sobel edge detection just uses different formulation to derive source image.

In this project, we use Canny Edge Detection to figure out edge points of the concerned liver region as shown in Figure 3.3





(a) (b)

Figure 3.3 (a) Detected Liver Image, (b) Result of Canny Detection

The result of the canny detection is the first process of the refined segmentation and in next step, we are going to calculate attitude between these edge points.

3.2.2 Altitude Calculation between Edge Points

We have already obtained the edge of the liver, only there is the last step remain that before we are going to mark the foreground and background label automatically. This step is altitude calculation between edge points and we will mark labels according to horizontal and vertical points because some foreground and background seeds are placed right and left sides of concerned points, other seeds are placed above and below sides of the edged point, so this process determine the edge point is placed horizontal or vertical. After this determination, the foreground and background labels can place accurately. We can see better the goal of this part in Figure 3.4

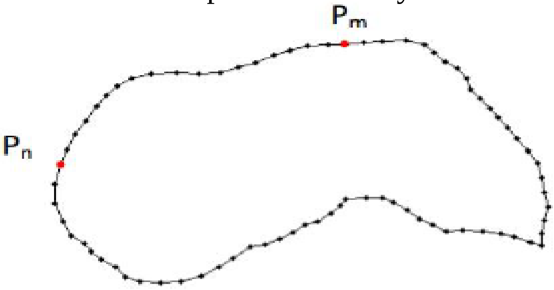
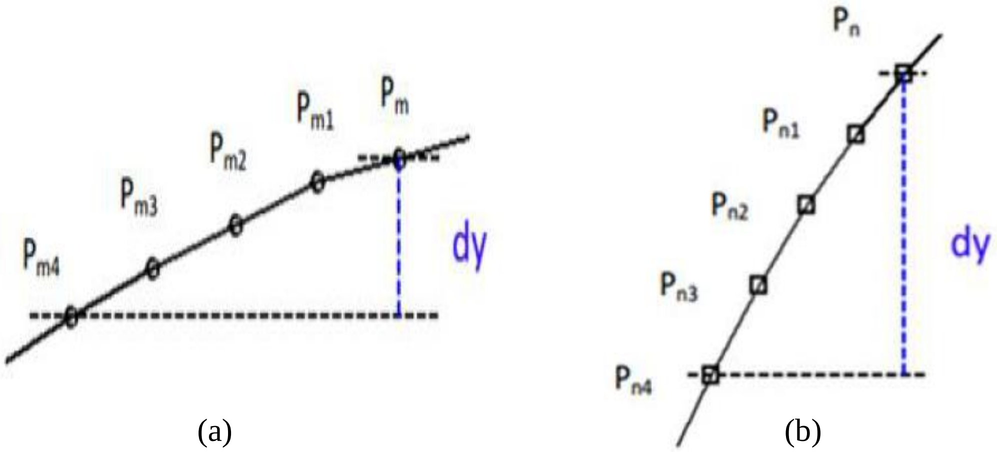


Figure 3.4 Edge Points for IGC

As seen as above, we need to detect that P_m and P_n points are placed vertical and horizontal to figure out that we are checking some neighbors of these points. In this case d_y represents the difference between two any different points on edge such as P_m and P_{m4}.



(a) (b)

Figure 3.5 (a) Horizontal and (b) Vertical Altitude Difference between Edge Points

In Figure 3.5 (a) and (b) shows d_y which is difference P_m and P_{m4} or P_n and P_{n4}. In next step, we will locate these foreground and background labels correspond to d_y difference. Roughly, There are three thresholding values T_h, T_1 and T_2. These thresholding values are assigned according to experience. So we will compare these thresholding and altitude difference (d_y) and this comparison will determine the destiny of labels. In the next chapter, we will mark labels using this information.

3.2.3 Marking Labels

The last step is IGC is marking label section. We are going to mark these background and foreground labels based on comparison these thresholding values (T_h, T_1 and T_2) and altitude difference d_y. If $d_y < T_h$, the seed points are placed in vertical, else the seed points are placed in horizontal. According to this comparison, foreground label is placed at the above of P_m with T_1 distance between label and P_m, background label is placed at the below of P_m with T_2 distance between label and P_m as seen as Figure 3.6 (a). In the other hand, we have determined that P_n is one of the vertical points on the edge. So the foreground label will be placed right side of P_n with T_1 distance between label and P_n, and background label will be placed left size of P_n with T_2 distance between label and P_n as shown Figure 3.6 (b)

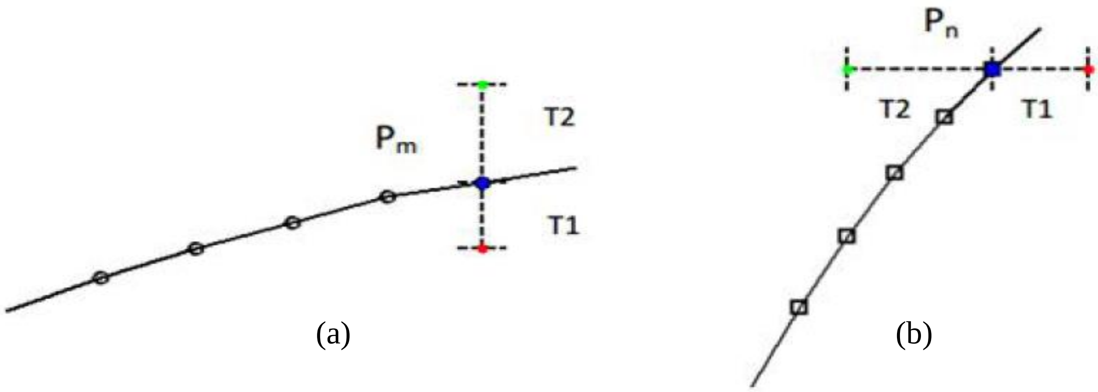


Figure 3.6 The background and foreground labels are marked for P_m in (a), for P_n in (b)

After this process now all background labels have surrounded the liver with T_2 distance and all foreground labels are located in the liver with T_1 distance. The results of Improved Grow-Cut Method is given in Figure 3.7(b)

(a) (b)

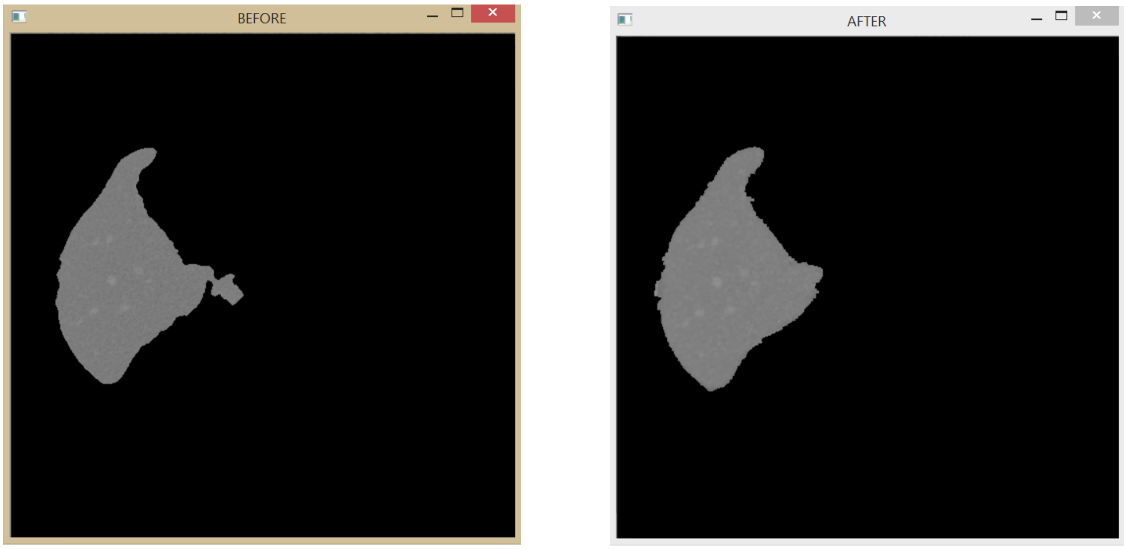
Figure 3.7 (a) The Liver Contour, (b) The Labelled Liver by IGC

3.3 Summary of Chapter 3

In this chapter, we tried to explained refined segmentation with details, Firstly we talked about Traditional Grow-Cut method. As we said before rough segmentation can be a reason of some under and over segmentation so some of the segmented images need to use refined segmentation to obtain better results. That is why we using refined segmentation with Grow-Cut. TGC is a segmentation technique based on region growing. Generally, TGC can give quite good results for segmentation. However TGC is an interactive method and in this project, all components are automatic methods. So we found out an Improved Grow-Cut method to overcome interaction problems.

In IGC, firstly we got the edge of the liver using Canny Edge Detection method than we calculate the altitude difference between each point and their fourth neighbors. Thus, we compare this difference with some thresholding values and we determined the points which are placed on the edge are horizontal or vertical. According to that method, we marked top and bottom of all horizontal points, and also we marked right and left sides of all vertical points. Hereby we obtained initial seed points without manual methods.

All foreground and background labels are marked in the seed template image by IGC. This automatic system gives to us that we can apply Grow-Cut method without any user interaction because we have already handled these initial background and foreground labels in the seed label template image and this image is shown in Figure 3.7 (b) In other words, homes of bacteria are ready and now they are just waiting for spreading. So there is no any obstacle to applying TGC method. Therefore, we are applying TGC methods and formulation to the image which needs for refined segmentation and marked by IGC. As seen as Figure 3.8 (a) this image had over-segmented so that is why we used IGC method and obtained the refined image is shown in Figure 3.8(b)



(a) (b)

Figure 3.8 (a) Over-segmented image, (b) Refined Image

Hereby we have obtained a well segmented liver sequences, a 2-D image consists of x and z-axis, but we have an image sequence so that mean we also have an extra axis is called y-axis as we know. This y-axis provides height to images and gives us obtaining volume opportunity. In the next chapter, we will need to use some toolkit to visualize the image sequence and we are going to talk about visualization.

4. Visualization

In this chapter, we are going to talk about 3-D data visualization methods, algorithms and implementation. Visualization points out the main idea of the subject using schematic forms and graphics. For example, a topography map of any country or profit graphics and some statistics of any company are some of the visualization methods. Visualization is a process of transformation from raw data to the visual form, basically, it points out the relationship between data based on calculations or measurements and visual forms such as colorization. For instance, we need to spend so much time to figure out accounting records of any company. Instead of the checking all the records, we can look the graphics of these records visually, we will have a general idea more easily. [4][47] [48]

Generally visualization in the medicine field, consist of three stages. Firstly, input which is refined segmented CT images to the VTK system, secondly one system reads all these images one by one using ImageSeriesReader() then at the last step, system create volume with these image sequence using ImageFileWriter(). These are shown in the Figure 4.1

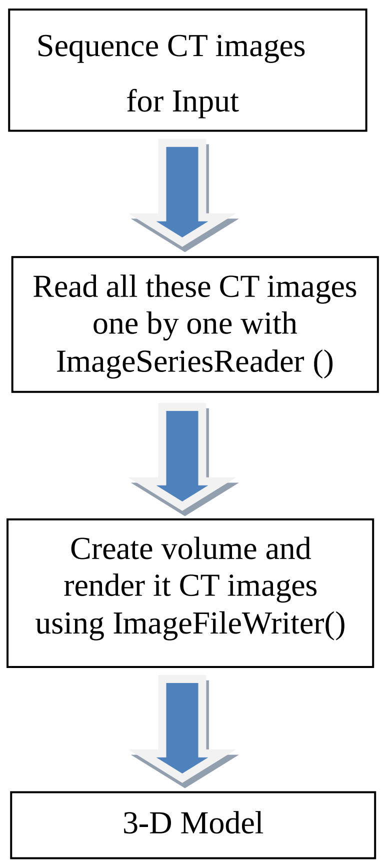


Figure 4.1 Framework of Visualization

Visualization process contains five stages:

1. Gathering data from numerical analysis, calculation, measurement devices, and so on.
2. All these methods and measurements give us data.
3. Obtained data transforms the visual form
4. The visual form is applied by mapping like a using brown colors for the high region in the map.
5. Demonstration of the new form of data

Visualization just cares about the results, how to obtain the data and measurements results in none of its business. So this process directly is related to intelligibility and plainness of the last form of data.

Particularly in the medicine field. Data visualization used to improve the understandability, make the data more interesting and handle the data easily, that is why we use visualization methods. Also, 3-D visualization assists to diagnosis any illness without surgical any intervention so it is a very significant step for treatment. By the wat visualization based various simulations are applied in the education system too, especially medicine staff education is a good sample of this education system. [4]

There are many visualization toolkits are developed. One of them is Visualization Toolkit which transforms the CT images to 3-D models using surface and volume visualization methods. Generally medical visualization uses the horizontal slices from body parts because any image has already contented 2-D size, these are x-axis and z-axis thus, we can add height with y-axis using these horizontal slice sequence as we introduced.

4.1 Introduction to Visualization Toolkit

Visualization Toolkit (VTK) is a library which is based on object modeling. VTK uses three modeling techniques to create an object-based design. These are object model, dynamic model, and functional model.

There are two methods for visualization, one of them is image order method another one is object order method. For example ray tracing method is based on image order method because we need to visualize the tracing of each ray in the continuous time. However, object order method tries to visualize any object step by step. [49]

Surface rendering and volume rendering techniques are two important terms in the visualization. The surface of the object only shows the surface attributes of the object using surface rendering but volume rendering demonstrates both of inside and surface of the object. One of an important component of rendering is colorization which contains RGB and HSV colorization systems. Generally in the segmentation methods especially in the medicine using grayscale colors but in the visualization also RGB color system can be important. RGB represents red, blue and green colors and each color consists of intensity combination of these three colors. HSV consists of hue, saturation, and value components. Hue contains dominant wavelength, saturation points out the rate of the wavelength in the color and value represents the brightness of the color. [50]

COLOR	*RGB*			*HSV*		
	R	*G*	*B*	*H*	*S*	*V*
BLACK	%0	%0	%0	0°	%0	%0
WHITE	%100	%100	%100	0°	%0	%100
RED	%100	%0	%0	0°	%100	%100
GREEN	%0	%100	%0	120°	%100	%100
BLUE	%0	%0	%100	240°	%100	%100
YELLOW	%100	%100	%0	60°	%100	%100
CYAN	%0	%100	%100	180°	%100	%100
MAGENTA	%100	%0	%100	300°	%100	%100

Table 3.1 RGB and HSV Values of Color

In the volume rendering process, transparency tissues can be visible using transparency coefficient and alfa value moreover. The different transparency coefficients make the surface tissues transparency and we can see the inside of the tissues. Also alfa value can be changeable between 0 and 1. In here 0 represents the maximum transparency and 1 represents opacity. Each tissue clusters such as bones, muscles, and skin tissues are categorized by different color or transparency in the volume rendering so each cluster is distinguishable to each other. [4]

4.1.1 Application Fields of Visualization Toolkit

VTK used to 3-D modeling in several fields because each sector needs to improve understandability in the short time that is why 3-D modeling techniques, charts and different data imaging methods are derived.

Except the 3-D medical imaging visualization, VTK used to various sector, some of them: Financial visualization with charts, geographic visualization and topographical mapping, 3-D object design, logo and some commercial logo creating, algorithm visualization, the realization of physical and mathematical formulation, and so on. [4]

4.2 3-D Modelling with Visualization Toolkit

Generally, VTK transforms the CT, MRI and X-ray images to 3-D models. 3-D modeling is quite an important step for before surgery plan. The creating from the medical imaging to 3-D modelling consists of four steps, these are:

1. Data reading
2. Creating iso-surface for each tissue
3. Model transformation from current space to world space
4. Model rendering

Generally, the format of the medical image is introduced using some functions of VTK and this data reading is the first step of the visualization with VTK. An isosurface is a composing surface method which creates a surface step by step. We are going to break down these steps:

4.2.1 Read the Input Data

Data reading process will be done via segmented Computed Tomography data in DICOM or PNG form. VTK only can read PNG and DICOM type images.

4.2.2 Create an Isosurface for each Classified Liver Tissue

VTK has an extensive information visualization framework, has a suite of 3D interaction widgets, supports parallel processing, and integrates with various one of the main processes of rendering is creating isosurface. Three methods are used to create the isosurface, these are dividing cubes [51], marching cubes [52] and volume rendering. Volume rendering process takes so much time for rendering, dividing cubes process is better for software based project. Marching cubes create many triangles for rendering so that is why marching cubes methods works better with low-resolution dataset.

4.2.3 Model Transformation into World Space

There are four coordinate systems for using the computer graphics. These are world, view, display and model. The world coordinate systems contain the coordinates of all things like objects, lights. View coordinates system represents the display of the camera. The attributes of the camera are defined by 4x4 transformation matrix to transform from world coordinates to view coordinates.

The Transformation matrix is:

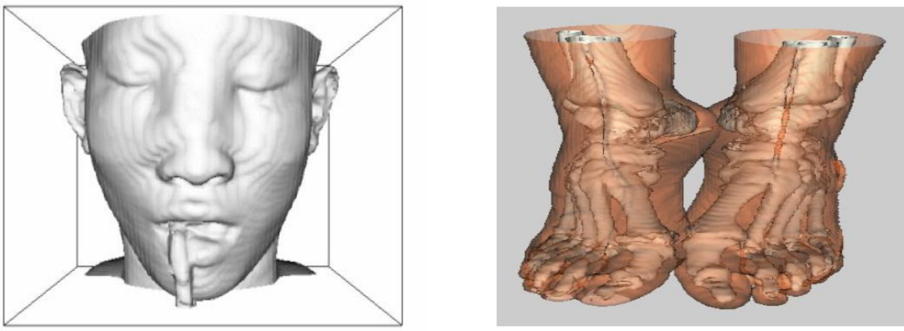
$$\begin{matrix} scaleX & 0 & 0 & t_x \\ 0 & scaleY & 0 & t_y \\ 0 & 0 & scaleZ & t_z \\ 0 & 0 & 0 & t_w \end{matrix} \qquad (4-1)$$

4.2.4 Model Rendering

Image order and object order methods widely used to render as we mentioned previously. Surface rendering and volume rendering are used for rendering of 3-D data.

Surface rendering is rendering the isosurfaces of an object. In medical imaging, the density value of the tissue assesses the each isosurface. In this method just volume is rendered by surface rendering and other all components are ignored. [53]

Volume rendering is a method which renders the surface and inside of the volume of any object. Also transparency coefficient and alfa value affect to see interior parts of the object and the transparency coefficient are used between 0 and 1. These values are directly reflected to display and we can see a transparency, semi-transparence or opaque 3-D models. 3-D model which is categorized by skin, muscle and bone systems but in this project, we already segmented all liver regions from rest of the image so we will just obtain the 3-D liver model. Hereby after all these processes we are closing to end of the project because now we have obtained an 3-D model.



(a) (b)

Figure 4.2 (a) Head CT Model Sample (b) Foot Model from Foot CT using VTK

4.3 Summary of Chapter 4

Visualization applications are developed in order to present the data to the user in a visual form, to improve the understandability of the data and to facilitate processing of data.

In this project, we have introduced a full automatic system which began automatic liver detection, continued with refined segmentation with Improved Grow-Cut and finalized with visualization using VTK.

In this chapter, we already introduced the VTK and we tried to explain some rendering methods such as surface rendering and volume rendering. In the project, we use the volume rendering with Dividing Cubes method. Actually, the Dividing Cubes method is derived to Marching Cubes. These segmented images are implemented by Dividing Cubes method. and the sample result is shown in Figure 4.3

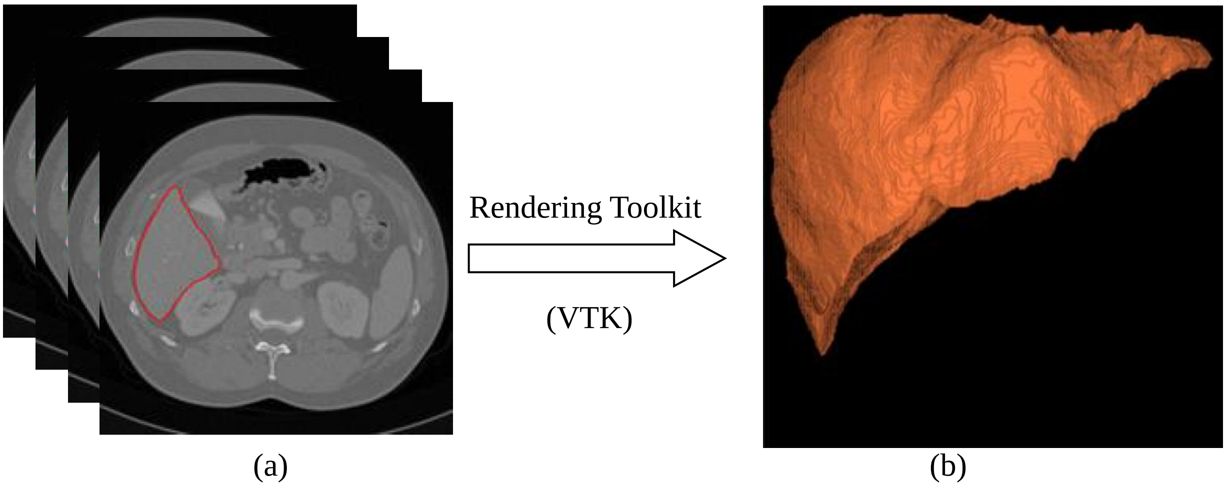


Figure 4.3 (a) Segmented CT image series (b) 3-D Liver Rendering from Segmented CT Images

The thesis is going to end with this last step of the process. The doctors or medicine staff can use the rendered liver model for diagnosing or treatment such as surgery planning, they can access the inside and surface of the liver that is why volume rendering is implemented to visualize the images. Thus, the diagnosing of the liver diseases can be quite simple and easy because the surface and internal parts of the liver are visible. In this manner, we have finished the automatic liver segmentation and visualization with VTK rendering project.

5. AUTOMATIC LIVER DETECTION AND VISUALIZATION PROJECT

We have already introduced Automatic liver detection stage, Improved Grow-Cut algorithm and Visualization with VTK. Now we are going to talk about the whole system. In this chapter, we will see all phases of the system with visuals. Firstly we used thresholding method based on the histogram. We assess a threshold interval for the liver which contains the color range of the liver so we eliminated irrelevant pixels from CT images. Consequently, we used some erosion methods for smoothing then we labelled all connected components and found the largest one. This largest connected component is our product of the first stage.

After these steps, we realized some images have some segmentation problems so to overcome that problem we used Grow-Cut method but this method is interactive to make it automatic we used Improved Grow-Cut method which generates automatic foreground and background labels. After these obtained refined CT image sequence we created a 3-D volume from these images. This is the summary of our project, now we will check the class and of the system, user interface, minimum system requirements, and the system which we used for implementation.

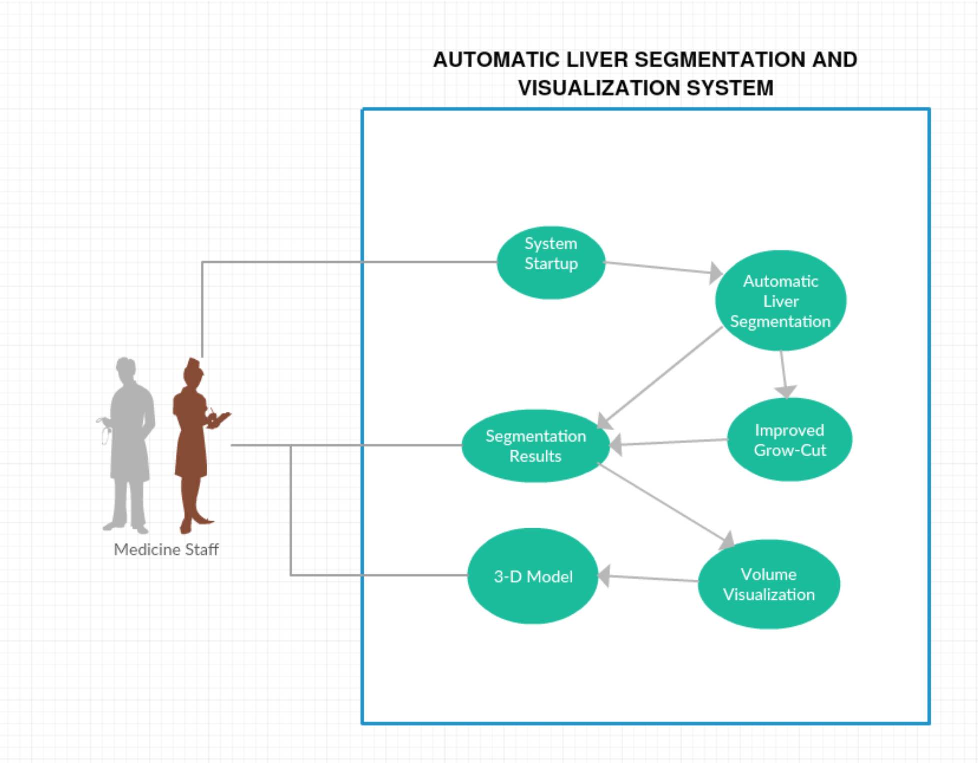


Figure 5.1 Use Case of the Project

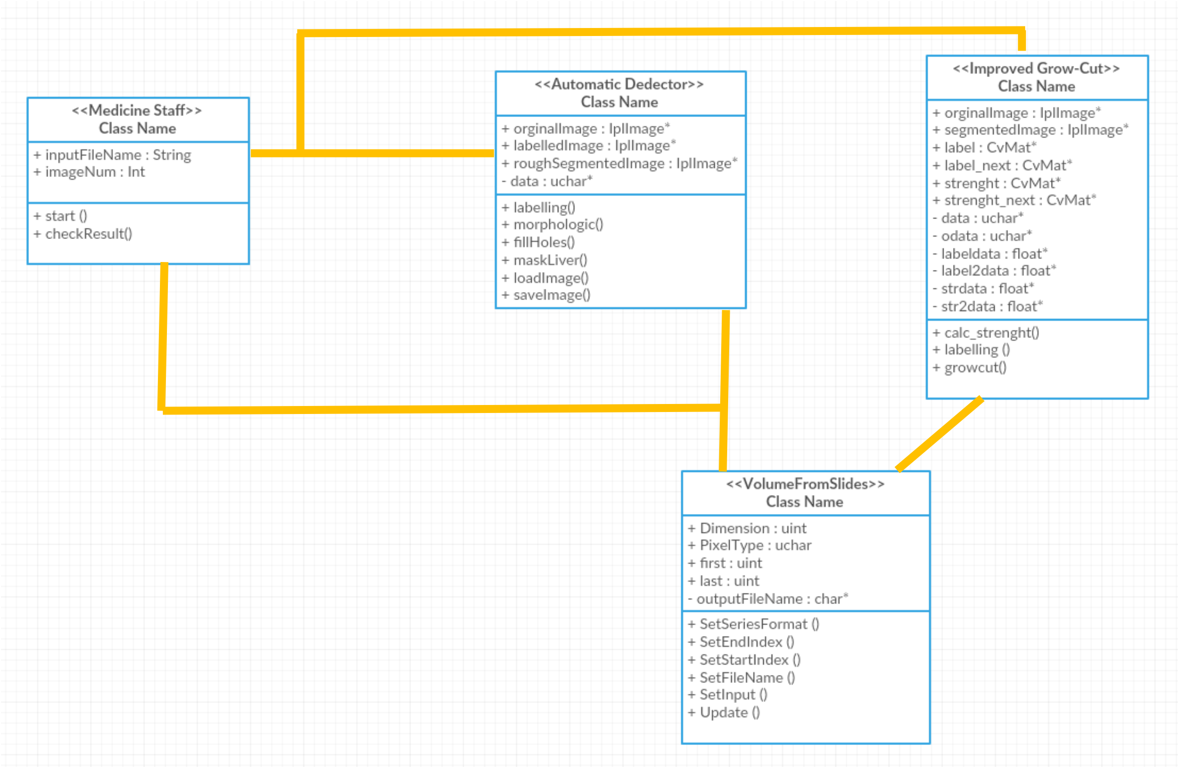


Figure 5.2 Class Diagram of the Project

Minimum System Requirements

Hardware:

1. Pentium IV or above
2. 2048 MB memory
3. 2 GB of disk space

Tools:

1. CMake 2.8 or above
2. Insight Toolkit 4.0 or above
3. Visualization Toolkit 5.0 or above
4. OpenCV 2.4 or above
5. ParaView 4.0 or above
6. Visual Studio 2016

Using Software and System in the Project for Implementation and Testing

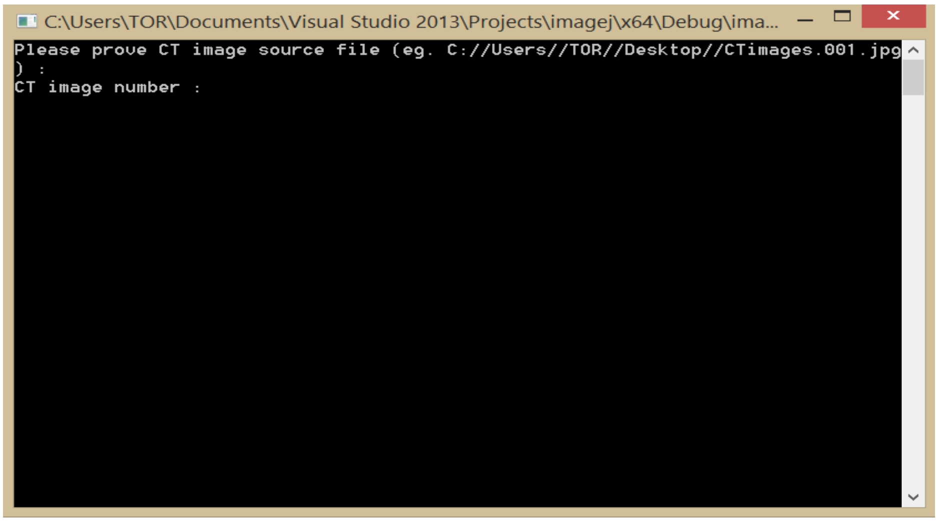
Hardware:

1. Intel Core i7-4700MQ CPU 2.40GHz
2. 8 GB memory
3. 64-bit Win 8.1 OS

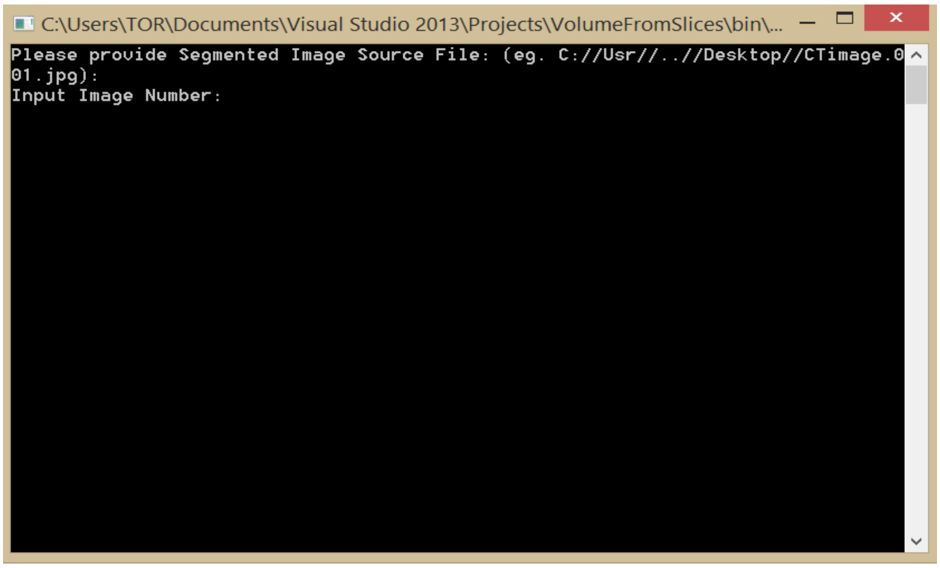
Tools:

1. MATLAB R2009a
2. CMake 3.2.1
3. Insight Toolkit 4.10
4. ParaView 4.0.1
5. Visualization Toolkit 6.3.0
6. Visual Studio 2013
7. OpenCV 2.4.8

System Interface and Results

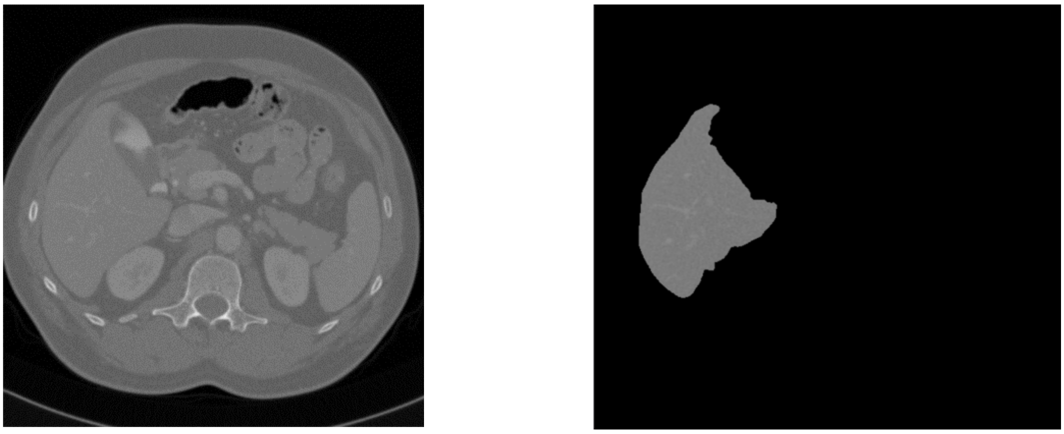


(a)



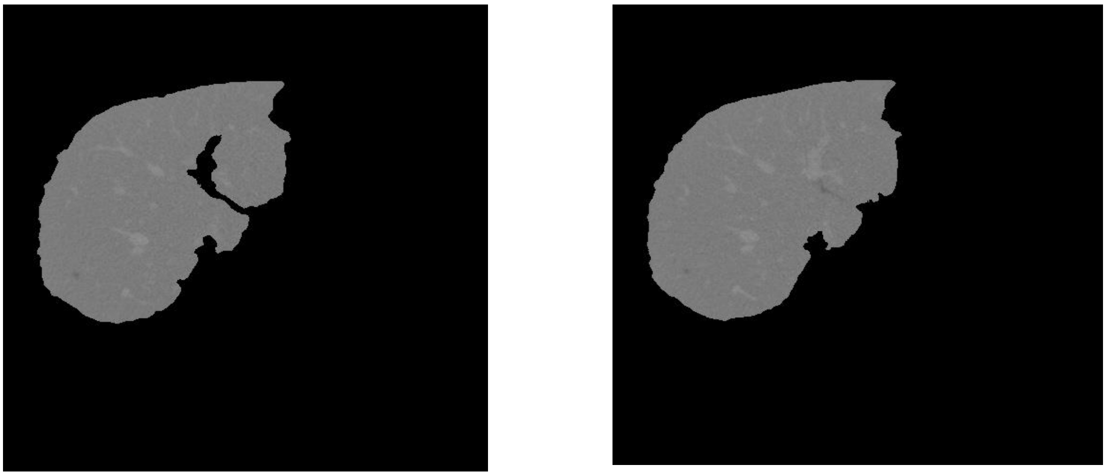
(b)

Figure 5.3 (a) Command Interface of Automatic Detection (b) Command Interface of Visualization



(a) (b)

Figure 5.4 (a) Original Image (b) Automatic Detected Image



(a) (b)

Figure 5.5 (a) Under-segmented Image (b) Refined Image

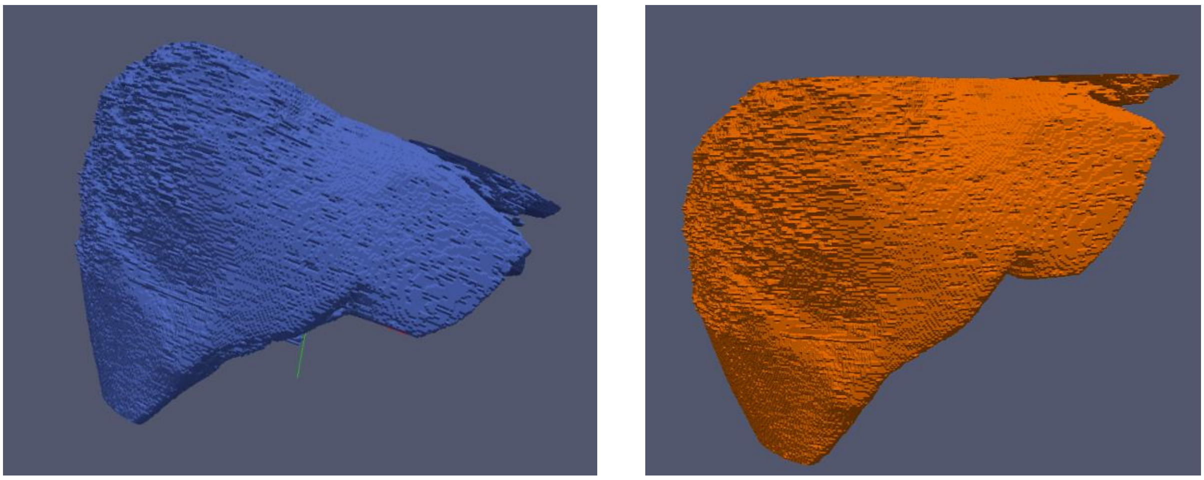


Figure 5.6 Rendered 3-D Liver Models

6. CONCLUSION

Each new day brings along developments. Particularly, computer vision fields are quite capable for new technologies. Also these new technological developments affect others and thus create a snowball effect. Segmentation and visualization are significant methods in the computer vision. Segmentation rendering means complete, some parts or objects can be identified in the image so we can focus the concerned region or object directly. Visualization simplifies to understand any dataset with graphics or charts.

Liver diseases are a widely problems among all demographics of people. That is why we implemented a system related to the liver. Also in this project, we tried to remove all interactive methods and manual intervention. Thus, we created a fully automatic liver segmentation and visualization implementation.

The implementation consists of three main phases: automatic liver detection, refined segmentation and volume rendering as we mentioned many times at the previous chapters.

In the automatic liver detection chapter, we used some thresholding methods based on histogram then we labeled this thresholded image and found the labeled largest components, which finally identifies the liver. Therefore, we obtained the liver regions from all abdominal CT images.

Secondly, we used Improved Grow-Cut method that is why some slices of the CT images were not segmented clearly, like some of them had under-segmentation or over-segmentation because of the blood vessels or similar close tissues. We assessed a threshold to solve these problems which checked the change of the liver region pixels. If pixel number of detected liver region increases or decreases over than the threshold value, we determined to refine concerned image slices with Improved Grow-Cut. Also, the method contains the automatic seed generation for Grow-Cut algorithm. That means we handled refined segmentation using Grow-Cut method without any manual process.

In the last step, we transformed these segmented liver slices to 3-D liver models using VTK. VTK is a stable and strong library which contains visualization functions. The volume rendering process also provides us the transparency so we can even check the inside of the liver from the surface and medical staff can use this system with diagnosing and planning corrective surgery before treatments.

This fully automatic system does not contain any manual interaction so we hope these systems will be used widely in the medical field and in the future these systems also can be combined with machine learning algorithms, thus the systems will recognize the diseases without doctor. Even some robotic systems can directly begin the treatment phase or surgery for patient.

Finally, the results of the system are quite satisfying. This project can be a significant mile stone for medical fields, similar to other proposed 3-D volume rendering and automatic detection methods.

References

[1] O. Zayane, B. Jouini, M. A. Mahjoub “Automatic liver segmentation method in CT images”, Canadian Journal on Image Processing & Computer Vision, volume: 2, issue: 8, 85 – 92, 2011

[2] H. Song, Q. Zhang and S. Wang, “Liver segmentation based on SKFCM and Improved GrowCut for CT images”, Bioinformatics and Biomedicine (BIBM), 2014 IEEE International Conference, IEEE, pp: 331 – 334, November 2014

[3] V. Vezhnevets and V. Konouchine, “GrowCut: Interactive multi-label ND image segmentation by cellular automata”, Proc. of Graphicon, pp: 150 – 156, 2005

[4] D.Ustunalan and Nese Erden, “3D Medical Visualization” [THESIS], Istanbul Tecnical University, 2009

[5] S. Chopra, MD, MACP. (January, 2014) Patient information: Cirrhosis[Online] http://www.uptodate.com/contents/cirrhosis-beyond-the-basics

[6] B.R. Bacon, MD and S.L. Schrier, MD, (April, 2015) Patient information: Hemochromatosis[Online] http://www.uptodate.com/contents/hemochromatosis-hereditary-iron-overload-beyond-the-basics

[7] S. Chopra, MD, MACP. (January, 2014) Patient information: Hepatitis C[Online] http://www.uptodate.com/contents/hepatitis-c-beyond-the-basics

[8] A. SF Lok, MD (November, 2015) Patient information: Hepatitis B[Online] http://www.uptodate.com/contents/hepatitis-b-beyond-the-basics

[9] C.-C. Lee, P.-C. Chung, Y.-J. Chen, Classification of liver diseases from CT images using BP-CMAC neural network, Proceedings of 9th International Workshop on Cellular Neural Networks and Their Applications pp: 118 – 121, 2005

[10] P. Campadelli, E. Casiraghi, S. Pratissoli, G. Lombardi, “Automatic Abdominal Organ Segmentation from CT images”, Electronic Letters on Computer Vision and Image Analysis volume: 8 issue: 1, pp: 1 – 14, 2009

[11] D. Maleikea, M. Noldena, H. P. Meinzera, et all, “Interactive segmentation framework of the Medical Imaging Interaction Toolkit”, Computer Methods and Programs in Biomedicine volume: 96 issue: 1, pp: 72 – 83, 2009

[12] F. Ritter, T. Boskamp, A. Homeyer, H. Laue, M. Schwier, F. Link, H. O. Peitgen, “Medical Image Analysis”, IEEE Pulse, volume: 2, Issue: 6, pp: 60 – 70, 2011

[13] M. McAullife (December, 2008), MIPAV User Guide [Online] http://mipav.cit.nih.gov/documentation/userguide/MIPAVUsersGuideVolume1.pdf

[14] G. Bradski and A. Kaehler, “Learning OpenCV Computer Vision with the OpenCV library”, O’Really Media, 2008

[15] B. Wu and R. Nevatia, “Detection and Tracking of Multiple, Partially Occluded Humans by Bayesian Combination of Edgelet based Part Detectors”, International Journal of Computer Vision, pp: 247 – 266, 2007

[16] J. P. Gonzalez and U. Ozguner, “Lane Detection using Histogram-based Segmentation and Decision Trees”, Intelligent Transportation Systems, pp: 346-351, 2000

[17] B. Smith, “Gestalt Theory: An Essay in Philosophy”, Foundations of Gestalt Theory, Munich and Vienna: Philosophia, pp:11 – 81, 1988

[18] L. Shapiro (Winter, 2005), Computer Vision Lectures, Unv. Of Washington [Online] https://courses.cs.washington.edu/courses/cse455/05wi/notes/ImageSegmentation.pdf

[19] N. Otsu, “A Threshold Selection Method from Gray-Level Histograms”, EEE Transactions on Systems, Man, and Cybernetics, volume: 9, issue: 1, pp:62 – 66, 1979

[20] S. S. Al-amri, N.V. Kalyankar and S.D. Khamitkar, “Image Segmentation by Using Threshold Techniques”, Journal of Computing, volume: 2, issue: 5, pp: 83 – 86, 2010

[21] F. Kurugollu, B. Sankur and A.E. Harmanci, "Color Image Segmentation using Histogram Multithresholding and Fusion", Image and Vision Computing volume: 19, pp: 915 – 928, 2001

[22] L. Shafarenko, M. Petrou, and J. Kittler, "Histogram-Based Segmentation in a Perceptually Uniform Color Space", IEEE Transactions on Image Processing, volume: 7, issue: 9, pp: 1354 – 1358, 1998

[23] T. Lindeberg, M.X. Li, "Segmentation and classification of edges using minimum description length approximation and complementary junction cues". Computer Vision and Image Understanding, volume: 67, issue: 1, pp: 88 – 98, 1997

[24] L. Barghout and J. Sheynin. "Real world scene perception and perceptual organization: Lessons from Computer Vision." Journal of Vision, volume: 13, issue: 9, pp: 709 – 709, 2013

[25] K. Fukunaga, L.D. Hostetler, "The Estimation of the Gradient of a Density Function, with Applications in Pattern Recognition". IEEE Transactions on Information Theory (IEEE) volume: 21, issue: 1 pp: 32 – 40, 1975

[26] R. Nock and F. Nielsen, "Statistical Region Merging", IEEE Transactions on Pattern Analysis and Machine Intelligence, volume: 26, issue: 11, pp:1452 – 1458, 2004.

[27] R. Adams and L. Bischof, "Seeded Region Growing", IEEE Transactions on Pattern Analysis and Machine Intelligence, volume: 16, issue: 6, pp: 641 – 647, 1994.

[28] R.M. Haralick and L.G. Shapiro, "Image Segmentation Techniques" , Computer Vision, Graphics, and Image Processing vol: 29, pp: 100 – 132, 1985

[29] S.L. Horowitz and T. Pavlidis, "Picture Segmentation by a Directed Split and Merge Procedure", Proc. ICPR, Denmark, pp: 424 – 433, 1974

[30] D. Chaudhuri and A. Agrawal, "Split-and-merge Procedure for Image Segmentation using Bimodality Detection Approach", Defence Science Journal, volume: 60, issue: 3, pp: 290 – 301, 2010

[31] L. J. Belaid and W. Mourou, "Image Segmentation: A Watershed Transformation Algorithm", Image Anal Stereol 2009, volume: 28, pp: 93 – 102, 2009

[32] S. Eddins (2002), Technical Articles and Newsletters, MathWorks [Online] http://www.mathworks.com/company/newsletters/articles/the-watershed-transform-strategies-for-image-segmentation.html

[33] M. Kass, A. Witkin and D. Terzopoulos, "Snakes: Active Contour Models", International Journal of Computer Vision, volume: 1 issue: 4, pp: 321 – 331, 1988

[34] S. -J. Lima, Y. -Y. Jeong, Y. –S. Hoa, “Automatic liver segmentation for volume measurement in CT Images”, Journal of Visual Communication and Image Representation, volume: 17, Issue: 4, pp: 860 – 875, 2006

[35] K. S. Suo, “Improved Fully Automatic Liver Segmentation Using Histogram Tail Threshold Algorithms”, ICCS'05 Proceedings of the 5th international conference on Computational Science, volume: 3, pp: 822-825, 2005

[36] T. Huang, G. Yang, and G. Tang, "A fast two-dimensional median filtering algorithm", IEEE Transactions on Acoustics, Speech, and Signal Processing, volume: 27, issue: 1, pp: 13 – 18, 1979.

[37] H. Samet and M. Tamminen, "Efficient Component Labeling of Images of Arbitrary Dimension Represented by Linear Bintrees", IEEE Transactions on Pattern Analysis and Machine Intelligence (TIEEE Trans. Pattern Anal. Mach. Intell.), volume: 10, issues: 4
pp: 579 – 586, 1988

[38] S. Wolfram, "Statistical Mechanics of Cellular Automata", Reviews of Modern Physics volume: 55, issue: 3, pp: 601 – 644, 1983

[39] H. Song, W. Kang, Q. Zhang, S. Wang, Kidney segmentation in CT sequences using SKFCM and improved GrowCut algorithm”, IEEE International Conference on Bioinformatics and Biomedicine (BIBM 2014), volume: 9, issue: 5, pp: 1 – 11, 2014

[40] P. Thakur, C. Lingam, “Generalized Spatial Kernel based Fuzzy C-Means
Clustering Algorithm for Image Segmentation”, International Journal of Science and Research (IJSR), volume: 2 issue: 5, pp: 165 – 169 , 2013

[41] D. Shiffman (2012), The Nature of Code [Online]
http://natureofcode.com/book/chapter-7-cellular-automata

[42] F. Berto and J. Tagliabue (Summer 2012), Stanford Encyclopedia of Philosophy, [Online]
http://plato.stanford.edu/cgi-bin/encyclopedia/archinfo.cgi?entry=cellular-automata

[43] T. Chen, M. Yagi, T. Hirai, et al, “Comparative study of interactive seed generation for growcut-based fast 3D MRI segmentation”, Signal & Information Processing Association Annual Summit and Conference (APSIPA ASC), pp: 1 – 4, 2014

[44] L. Gray, "A Mathematician Looks at Wolfram's New Kind of Science." Notices of the American Mathematical Society, volume: 50, issue: 2, pp: 200 – 211, 2003.

[45] P. Ghosh, S. K. Antani, L. R. Long, et al "Unsupervised Grow-Cut: Cellular Automata-Based Medical Image Segmentation", Healthcare Informatics, Imaging and Systems Biology (HISB), 2011 First IEEE International Conference, pp: 40 – 47, 2011

[46] H. Men and X. Zhao, "Microbial Growth Modeling and Simulation Based on Cellular Automata", Research Journal of Applied Sciences, Engineering and Technology volume: 6 issue: 11, pp: 2061 – 2066, 2013

[47] M. Friendly (August 2009), Milestones in the history of thematic cartography, statistical graphics, and data visualization [Online] http://www.math.yorku.ca/SCS/Gallery/milestone/milestone.pdf

[48] F. Viegas and M. Wattenberg (April 2011), How to make data look sexy, CNN [Online] http://edition.cnn.com/2011/OPINION/04/19/sexy.data/

[49] W. Schroeder, K. Martin, B. Lorensen, "Visualization Toolkit: An Object-Oriented Approach to 3D Graphics, 4th Edition", Kitware, 2006

[50] A. R. Smith, "Color Gamut Transform Pairs", ACM SIGGRAPH Computer Graphics, volume: 12, issue: 3, pp: 12 – 19, 1978

[51] Carr H, "(No) More Marching Cubes", IEEE / Eurographics Symposium on Volume Graphics 2007, pp: 81 – 90, 2007

[52] W. E. Lorensen, H. E. Cline, "Marching Cubes: A High Resolution 3-D Surface Construction Algorithm", Computer Graphics, volume: 21, issue: 4, pp: 163 – 169, 1987

[53] X. Papademetris (December 2006), "Medical Image Analysis with VTK: A Tutorial", Insight Journal [Online] http://www.insight-journal.org/download/viewpdf/137/2228/bitstream

[54] I. Wolf, M. Vetter, I. Wegner, et al, "The Medical Imaging Interaction Toolkit", Medical Image Analysis, volume: 9, issue: 6, pp: 594 – 604, 2005