Segmentation of Prostate by Active Contour Model

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To Neha, the love of my life...!
Arsalan

Abstract

Prostate cancer is most common cancer among men. There has been a lot of research to detect the cancer at the earliest possible stage. A number of methods are available and used to detect tumor, but scientific community is always curious to find a compuationally cheap, reliable, robust and more accurate segmentation of prostate. This report proposes semi automatic segmentation of different zones of prostate as well as tumor using Active Contour Model. The report starts with brief introduction of Prostate and discusses related biological pre-requisites to understand the aim of the project. The report then describes active contour model and theory behind to let reader's know how it works. The algorithm is implemented on MATLAB and an application is created. The report finally ends with guiding the user with application.

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Chapter 1

Introduction

Human Body is the most fantastic and perfect machine. The more we learn it, the more we are surprised. It's a perfectly designed system comprising of different sub-systems. These subsystems comprising of different organ systems work together in a complex, dynamic and efficient manner for its perfect health.

The prostate is one of the important body part , its a walnut-sized gland located between the bladder and the penis. The prostate is just in front of the rectum. The urethra runs through the center of the prostate, from the bladder to the penis, letting urine flow out of the body. The prostate secretes fluid that nourishes and protects sperm. During ejaculation, the prostate squeezes this fluid into the urethra, and it's expelled with sperm as semen [3].

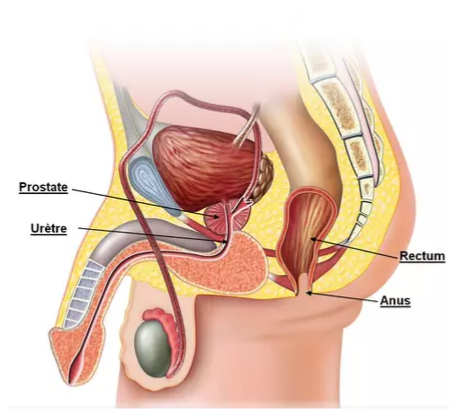


Figure 1.1: Prostate location [3]

Prostate cancer is one of the most common types of cancer in men. Usually prostate cancer grows slowly and is initially confined to the prostate gland, where it may not cause serious harm. However, while some types of prostate cancer grow slowly and may need minimal or even no treatment, other types are aggressive and can spread quickly.

It's not clear what causes prostate cancer. Doctors know that prostate cancer begins when some cells in your prostate become abnormal. Mutations in the abnormal cells' DNA cause the cells to grow and divide more rapidly than normal cells do. The abnormal cells continue living, when other cells would die. The accumulating abnormal cells form a tumor that can grow to invade nearby tissue. Some abnormal cells can also break off and spread (metastasize) to other parts of the body [2].

In order to understand the project, we need to understand the anatomy of prostate. The next section describes briefly the anatomy of Prostate.

1.1 Anatomy of Prostate

The prostate is the largest accessory gland in the male reproductive system. The prostate is positioned inferiorly to the neck of the bladder and superiorly to the external urethral sphincter, with the levator ani muscle lying inferolaterally to the gland[3].

The prostate is commonly described as being the size of a walnut. Roughly two-thirds of the prostate is glandular in structure and the remaining third is fibromuscular. The gland itself is surrounded by a thin fibrous capsule of the prostate. This is not a real capsule; it rather resembles the thin connective tissue known as adventitia in the large blood vessels. The prostate is divided into three zones [1]:

- **Central zone** – surrounds the ejaculatory ducts, comprising approximately 25% of normal prostate volume. The ducts of the glands from the central zone are obliquely emptying in the prostatic urethra, thus being rather immune to urine reflux.

- **Transitional zone** – located centrally and surrounds the urethra, comprising approximately 5-10% of normal prostate volume.

- **Peripheral zone** – makes up the main body of the gland (approximately 65%) and is located posteriorly. The ducts of the glands from the peripheral zone are vertically emptying in the prostatic urethra; that may explain the tendency of these glands to permit urine reflux. That also explains the high incidence of acute and chronic inflammation found in these compartments, a fact that may be linked to the high incidence of prostate carcinoma at the peripheral zone. The peripheral zone is mainly the area felt against the rectum on Digital Rectal Examinations (DRE), which is of irreplaceable value.

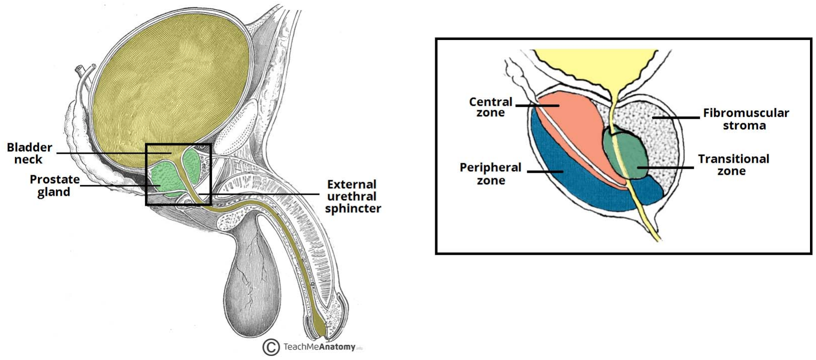


Figure 1.2: The three zones of prostate [3]

The arterial supply to the prostate comes from the prostatic arteries, which are mainly derived from the internal iliac arteries. Some branches may also arise from the internal pudendal and middle rectal arteries [5, 3].

Venous drainage of the prostate is via the prostatic venous plexus, draining into the internal iliac veins. However, the prostatic venous plexus also connects posteriorly by networks of veins, including the Batson venous plexus, to the internal vertebral venous plexus[3].

To give 3D demonstration of Prostate, th following figure will help. It is important to understand these zones in order to understand the next chapter and the effeciency of the algorithm to segment the zones of prostate.

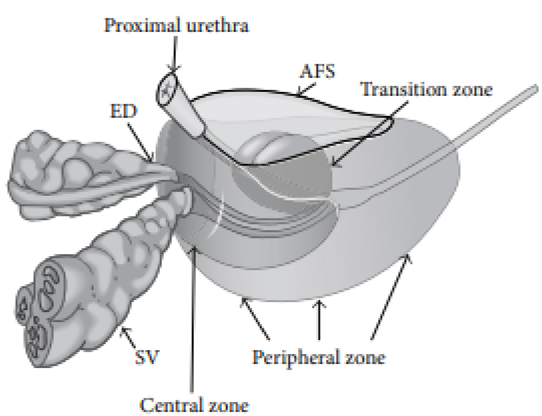


Figure 1.3: The 3D image of prostate showing different zone locations [2]

The prostate receives sympathetic, parasympathetic and sensory innervation from the inferior hypogastric plexus. The smooth muscle of the prostate gland is innervated by sympathetic fibres, which activate during ejaculation.

1.2 Prostatic carcinoma

It is most commonly diagnosed cancer among men. The malignant cells commonly originate from the peripheral zone, although carcinomas may arise (more rarely) from the central and transition zones too.

However the proximity of the peripheral zone to the neurovascular bundle that surrounds the prostate may facilitate spread along perineural and lymphatic pathways, thus increasing the metastatic potential of these tumors. Malignant cells may invade adjacent structures (bladder, seminal vesicles) and/ or lymphatic and blood vessel routes to give distant [5]. metastases[1]. We were given task to deal with an adenocarcinoma type of cancer for prostate. It is a type of cancer that arises in the cells of glands. Most cells in the prostate gland are of the glandular type, which means that adenocarcinoma is the most common type of cancer to occur in the prostate. Cancer occurs when the genes of a cell become abnormal (mutation), causing the cell to multiply and interfere with the normal function of a tissue.

Once the cancer reaches a certain size, the abnormal cells can spread to other parts of the body and cause cancerous tumours to grow. This phenomenon is known as metastasis. If a tumour is capable of spreading to other parts of the body in this way, it is called malignant. Adenocarcinoma of the prostate is malignant, however many types grow extremely slowly, and so are unlikely to spread before a man dies of other causes [3].

In order to have an intuition about prostate cancer, the below figure will help.

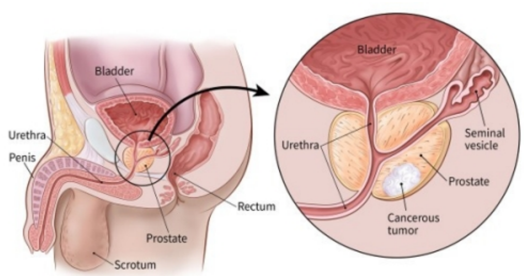


Figure 1.4: The tumur is shown in white color. [5]

[1]metastases means the development of secondary malignant growths at a distance from a primary site of cancer

Chapter 2

Active Contour Model

This chapter covers the most important concept of the project which is the algorithm we used to segment the prostate images. It is important to understand the algorithm in order to fully understand the project.

Active contour model is also known as snakes. It is very popular among Computer Vision community. This algorithm has enormous applications from Autonomous driving cars to medical imaging. It is one of very reliable and easy to implement algorithm available. Snake is an energy minimizing algorithm, which means it works on some optimization technique to find the minimum energy. We need an energy function, that matches our intuition about how good the segmentation is.

The question here arsises about what actually energy is. and how to think about energy in order to understand. Let define energy as [4]:

$$E(c) = E_{internal}(c) + E_{external}(c) \tag{2.1}$$

In this equation, the internal energy function depends only on the shape of the curve. The external parameter depends on the image intensities. Now lets talk about the internal parameter in detail.

2.1 Internal Energy

The general idea is that relaxed shape have low energy and twisty shapes with too many curves have lot os energy. In physics terminology, we can say that smooth curves have low tension and highly twisted curves have more energy. The following figure will give the idea.

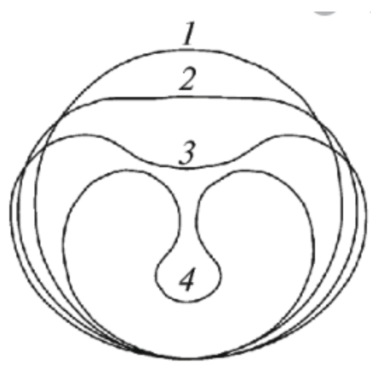


Figure 2.1: Different curves having different energies. Curve 1 has least energy and curve 4 has most energy.

To describe this idea mathematically we use the following equation [4]:

$$E_{internal} = \int_a^b (\alpha||c'(s)||^2 + \beta||c''(s)||^2)ds \tag{2.2}$$

The α parameter here is defines the tension or strechness of the curve. Note that it scales the single derivative of the curve s. The low α means, the curve will be less curvy and low energy ultimately. The double derivative can be thought of as describing the twisting capability of the curve. The double derivative highlights oscillation behaviour in snake by taking difference in the points placements of curves.

2.2 External Energy

The external energy of the curve in the image depends on the image itself. It is used to detect the edges. The mathematical defination can be written as [4]:

$$E_{external} = \int_a^b -||\nabla Ic(s)||^2 ds \tag{2.3}$$

The gradient of any two nearby pixels is actually the difference of the intensity values f the two pixels. The above formula can be written as:

$$E_{external} = \int_a^b -[(\frac{\delta I}{\delta x}(x(s), y(s)))^2 + (\frac{\delta I}{\delta y}(x(s), y(s)))^2]ds \tag{2.4}$$

If there is no edge in the image there will be no difference in intensity values of the neighbouring pixels and the gradient will be equl to zero. However, If there is any edge, the gradient will have some good positive value and multiplication with minus sign outside the norm will make it negative, hence energy will be lowest.

In short, the lowest value of External energy indicates a edge and value of Internal energy explains the least curviness and tension in the curve. The problem is to find the least $E(c)$. This is how active contour model works. This was the simplest idea of Active contour model, ofcourse there are much more complicated modification in this idea to get the maximum performance from the model while on implementation and that requires quite rigorous mathematical practice. However, still the basic equations and theory we describes remains always relevent.

Chapter 3

Implementation on MATLAB

This Chapter discusses the methodolgy of implementing the algorithm to find the desired results successfully. The chapter discusses challenges faced and limitation of MATLAB in implementation.

To carry out this project, we decided to use MATLAB app designer. This is a very powerful tool and it allows us to package the application for matlab apps for future. Its like creating a MATLAB toolbox. The MATLAB app designer is relatively a new feature, so it has some limitations. Also, some of the functions are not compatible with GUI function and Matlab provides parrallel functions to make it work. However it was a great experience and tool is very reliable and user friendly and easy to learn.

The project was divided into three main tasks. These are shown in below figure.

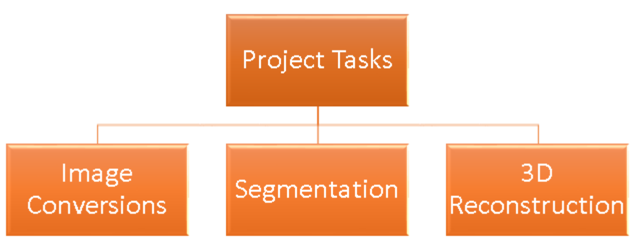


Figure 3.1: Project subdivided into 3 main tasks.

3.1 Image Conversions

We were supposed to convert Dicom images to JPEG, JPEG to Dicom. While converting, the information from dicom images regarding patients was important to extract and deal with. Because in JPEG format, there is no replacement and compatibility to save the patient information. The important data was extracted from the Dicom images by accessing the cell array 'info_original', and saved in a seperate folder named 'metadata'. The task of converting from JPEG back to Dicom was acheived by extracting the information from metadata file and concatenating it with the respective image.

To ananymize the patient data from Dicom images, we extracted related information from the 'info_original' cell array and measured length of each data and replaced it with 'x'.

All of these operation were designed with default folder creation in case if there is no folder existing. These operations were designed to perform on the whole folder of input image.

3.2 Segmentation

This is the trikiest part of the project. We faced a problem while drawing the initial contour for segmentation. The MATLAB app designer UIAxes, which deals with the images does not supports the freehand function. We solved this problem by creating a figure outside GUI and performing Active contour segmentation on it, and then showing the results back to the GUI.

The Active contour function in matlab was used. The function takes multiple parameter. They are as follows:

1. **Image** – The image on which there is object to be segmented
2. **Mask** – The mask is region of interest. The is input we give when we draw the initial contour. The size of mask must match the size of the image A.
3. **No of Iterations** – The no of iterations are decided on the basis of accuracy needed.
4. **Method** – Active contour method used for segmentation, specified as 'Chan-Vese' or 'edge'. We used edge model.
5. **Degree of Smoothness** – Degree of smoothness or regularity of the boundaries of the segmented regions, specified as the comma-separated pair consisting of 'SmoothFactor' and a positive number. Higher values produce smoother region boundaries but can also smooth out finer details. Lower values produce more irregularities (less smoothing) in the region boundaries but allow finer details to be captured. The default smoothness value is 0 for the 'Chan-Vese' method and 1 for the 'edge' method. It refers to α parameter as discussed in previous chapter.

The prompt box were created to ask the user regarding neccessary parameters that were subject to change with the changing input images.

3.3 3D Reconstruction

After the images were segmented and saved according to there category. Each semented image was saved according to its instance / slice no. The 3D draw function takes each slice of segmented image in the order of there slice no and puts them over each other, thus creating a 3D object. The 3D draw function was originally fetched from github and modified according to our needs.

In summary, the following flow chart demonstrates the working of Matlab code Application. The segmentation for each slice was repeated to construct a good 3D image of the object.

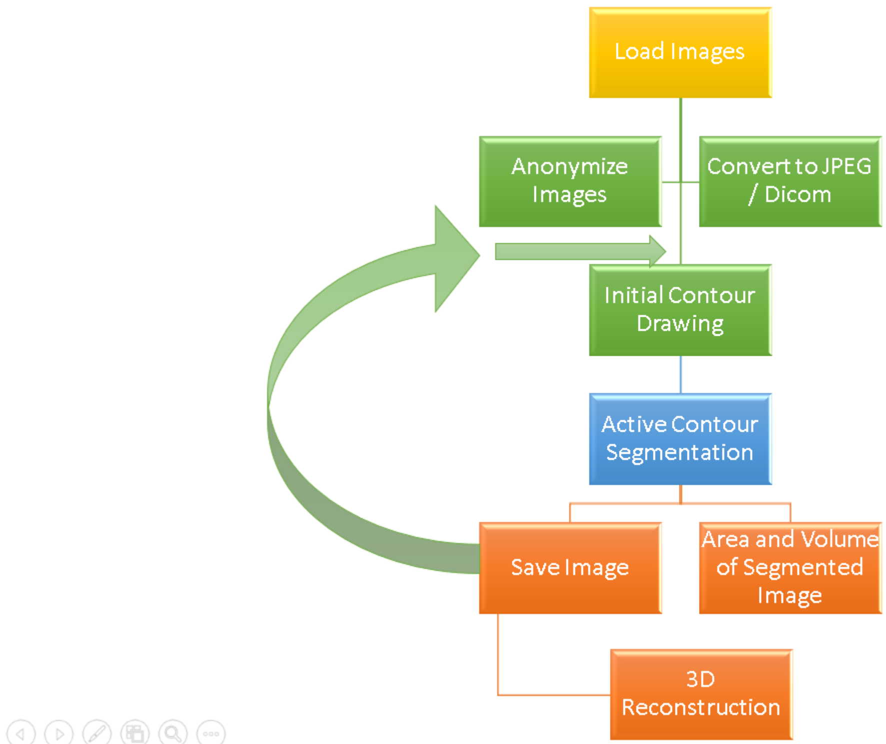


Figure 3.2: The flow chart demonstrating the implementation of Active contour model and 3D reconstruction on MATLAB. The arrows signifies iterations neccessary to carry out enough segmentation to achieve 3D reconstruction.

Chapter 4

User Guide for Prostate Segmentator

This chapter guides the user how to use the application and executable file.

The application was built on MATLAB app designer. It is relatively new platform and is different from GUIDE. App Designer is an interactive development environment for designing an app layout and programming its behavior.

Now lets start with the aplication. When you run the program the following figure will appear in the screen.

Figure 4.1: The main window of appication

To upload the images, we use the button Load image folder in yellow colour. It will load the whole folder of dicom images in our database. Select the database you want to open. Donot select folder with other formats exept Dicom. This button is not programmed to work for other image types. The purple color buttons with next and previous images written on them will navigate you through different slices / instances of MRI. The data will change accordingly.

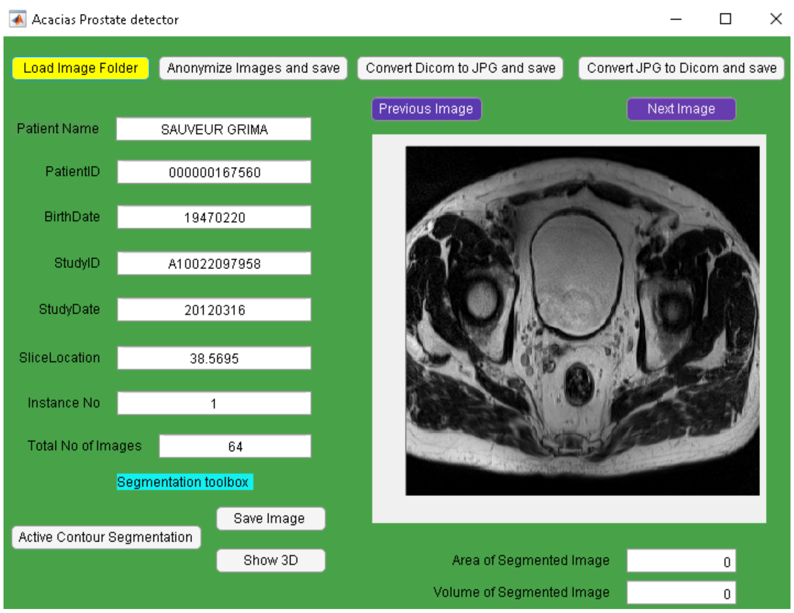


Figure 4.2: The axes showing first image by defualt and patient data has been loaded.

To ananymize the images, we just click on Anonymize images and save button. It will automatically create folder if there aint exist any and save images in it. You can check them by loading anonymized folder. The following figure will appear:

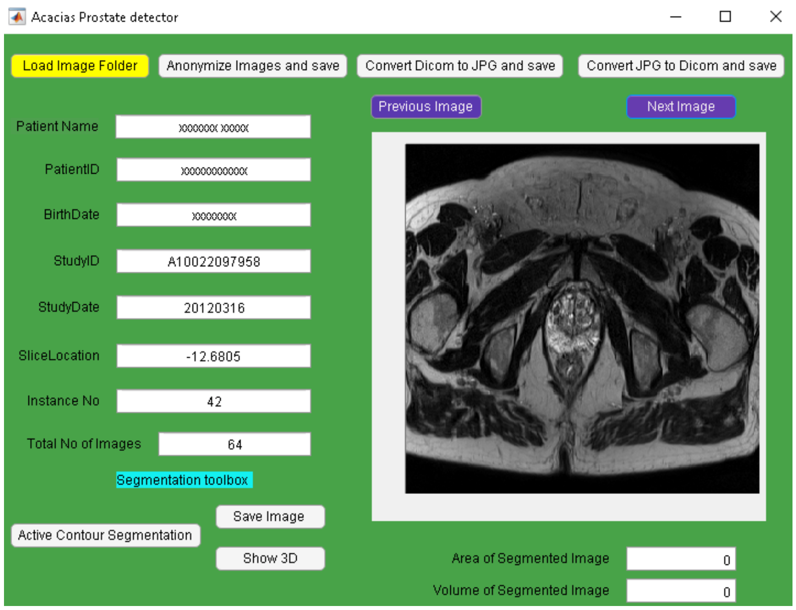
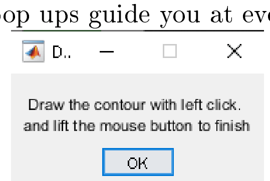


Figure 4.3: Anonymized images are saved in a seperate folder in the working directory, where they can be accessed using Load folder option.

In the same way, we can convert Dicom to JPEG and vise versa. The folder to save these images will be automatically created. The next step is to go for segmentation. In the segmentation toolbox, Select Active Contour Segmentation, the following window will prompt to advise you to draw initial contour / mask.

Figure 4.4: The pop ups guide you at every stage like this.



Now you will see the prompt window asking for the number of iterations. The default value for no of iterations has been set up to 200. Input the no of iterations you want, and click OK.

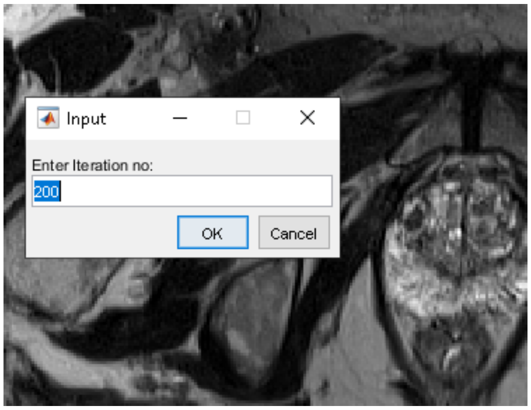


Figure 4.5: Input parameters are must be positive number. and it should not be zero.

After no of iterations, a second prompt box will appear asking you for the smoothness factor. The default value for smoothness factor is 1.5. Please enter your desired smoothness factor and click OK.

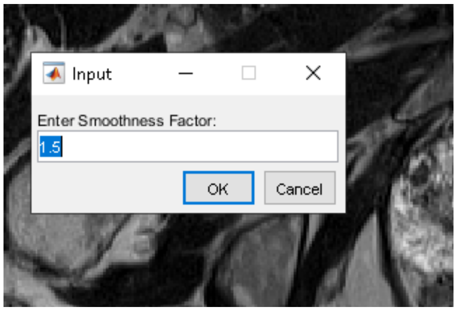


Figure 4.6: The smoothness factor should be positive number and not be zero. The default smoothness value is 0 for the 'Chan-Vese' method and 1 for the 'edge' method.

Now, a prompt box will pop us to ask how you want to draw initial contour for active contour problem. There are three ways, either you select freehand or circle or rectangle. Select your desired method and draw contour.

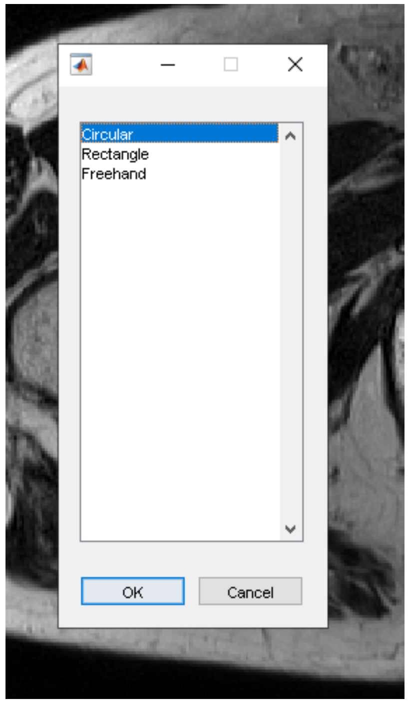


Figure 4.7: The desired method of drawing intial contour must be selected.

The contour can be drawn by pressing the left click of mouse and moving. When you release click that means you are done and contour will close itself.

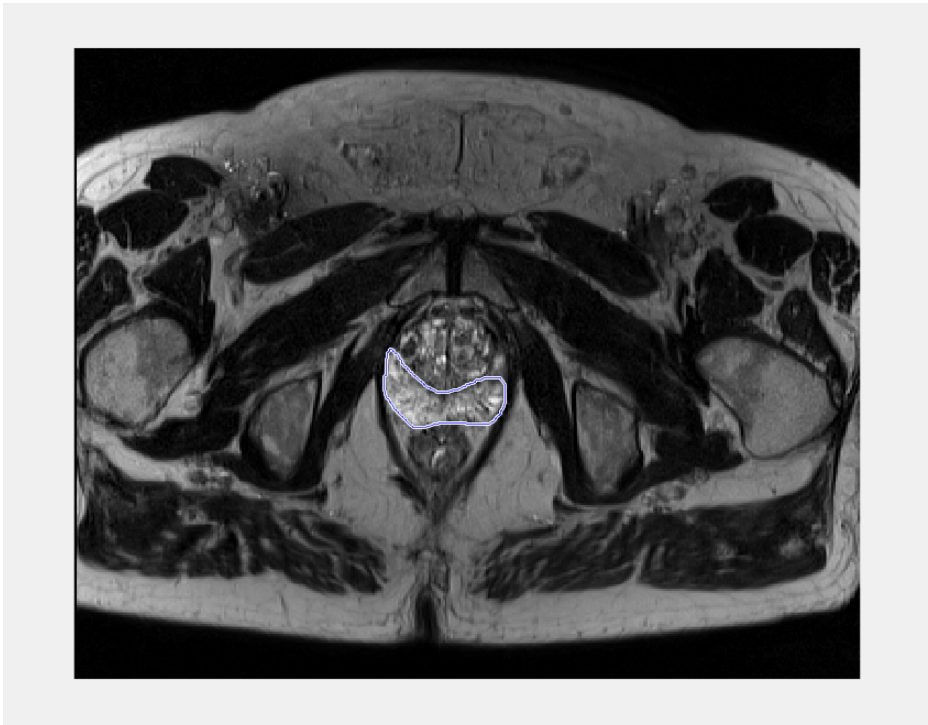


Figure 4.8: The blue line is initial contour drawn. It is done to segment peripheral zone.

Now you need to wait sometime, probably 30 seconds to one minute for algorithm to work. Once it is done the following figure will appear with the segmented image. If you like the segmented image you can move to click save the image other wise repeat the process by changing parameters to get the suitable segmentation.

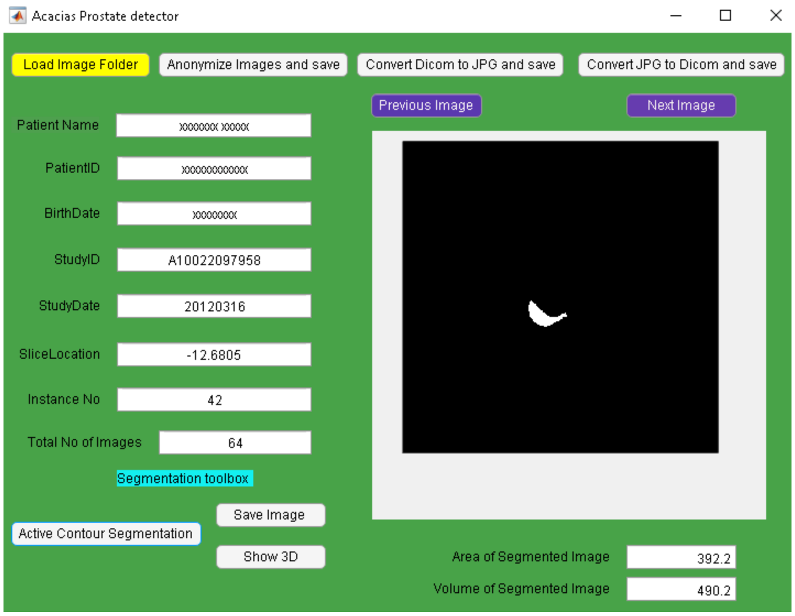


Figure 4.9: The segmented image is shown on the User Interface. The white area indicates the segmentation,

Now click the save button to save the segmented image. Once you click it, the following figure will prompt asking you to categorize what does the segmented image refers to. Please select the correct category. It will save image in that respected folder in segmented images.

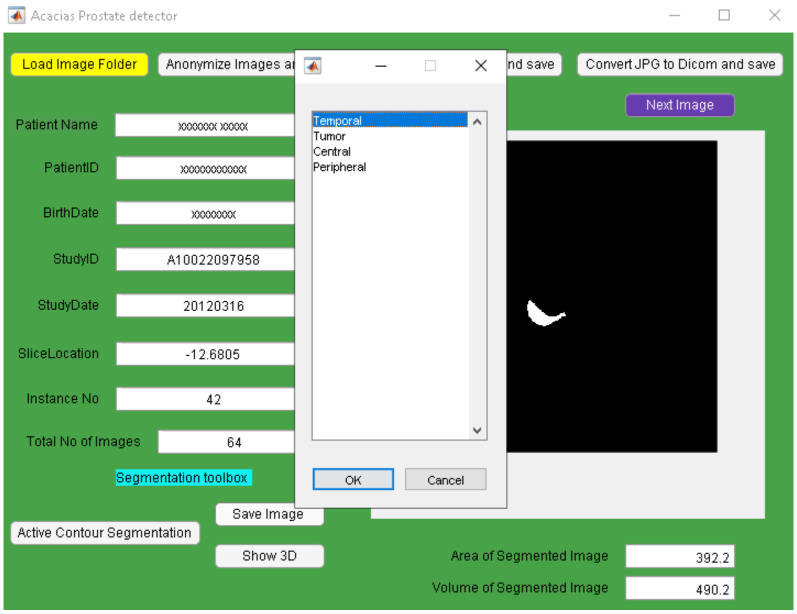


Figure 4.10: The saving category helps in to categerozi images for 3D reconstruction.

The knowlegde of slice / instance is important while saving the segmented image. It will be used for 3D reconstruction. Confirm the instance no in the prompt box and click OK.

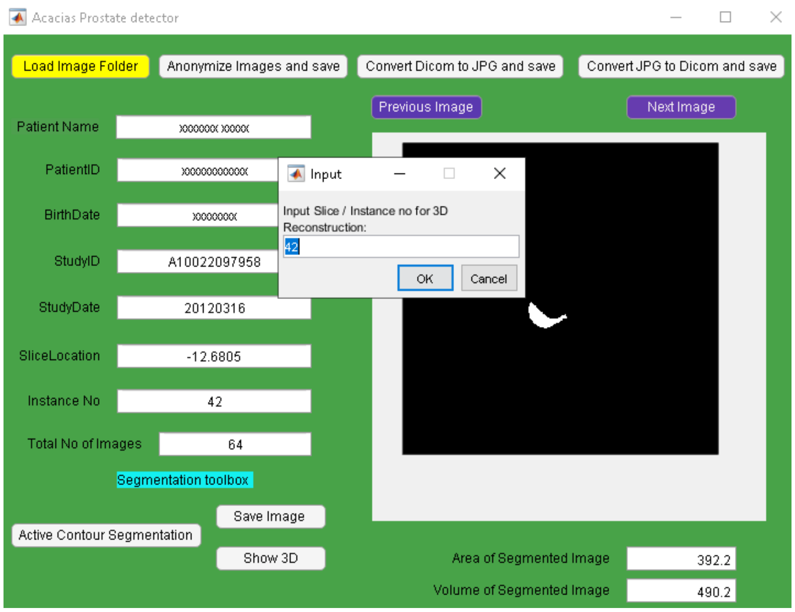


Figure 4.11: The default value is taken from current index. You just need to confirm in most cases, if you dont want to manipulate results.

The area and volume of segmented image is also shown at the bottom of the window. It is caculated by the product of white pixels in segmented image by Pixel spacing of dicaom image. The volume of segmented image was calculated by the product of area calculated by pixel thickness of Dicom image.

3D Reconstruction

Now you have to repeat this process for reasonable amount of times for each instance / slice. Once you have enough segemnted images for the particular category, you can move to produce 3D image.

Click on show 3D button and select the segmented folder. Within segmented folder, you will see 4 subfolders of Tumur , Central , Peripheral and Temporal zones. Select the desired folder and figure with 3D of particular object (like tumor) will appear.

The figure below gives 3D reconstruction of Peripheral zone of the Prostate.

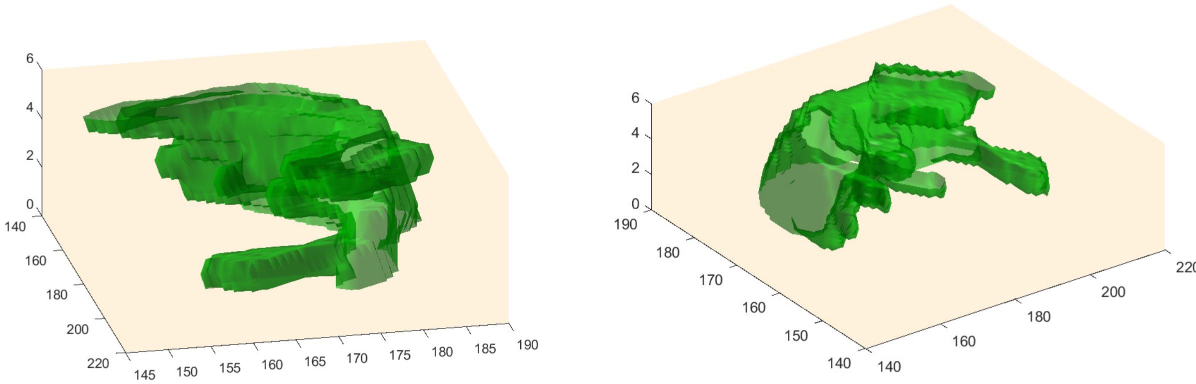


Figure 4.12: 3D reconstruction of Peripheral zone. The peripheral zone is u shaped as it can be seen.

The 3D reconstruction of Central zone is shown in below figure.

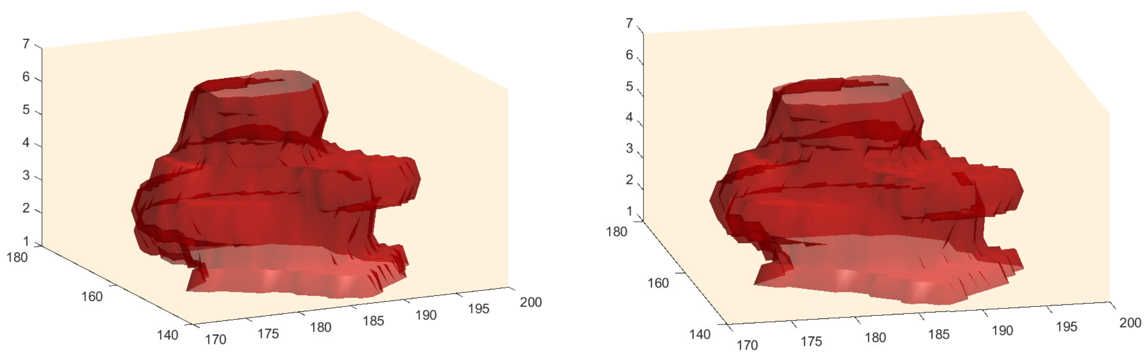


Figure 4.13: 3D reconstruction of central zone. The central zone is oval in shape mostly. However, more accurate results can be obtained by more careful segmentation.

The 3D reconstruction of Transitional / Temporal zone is shown in below figure.

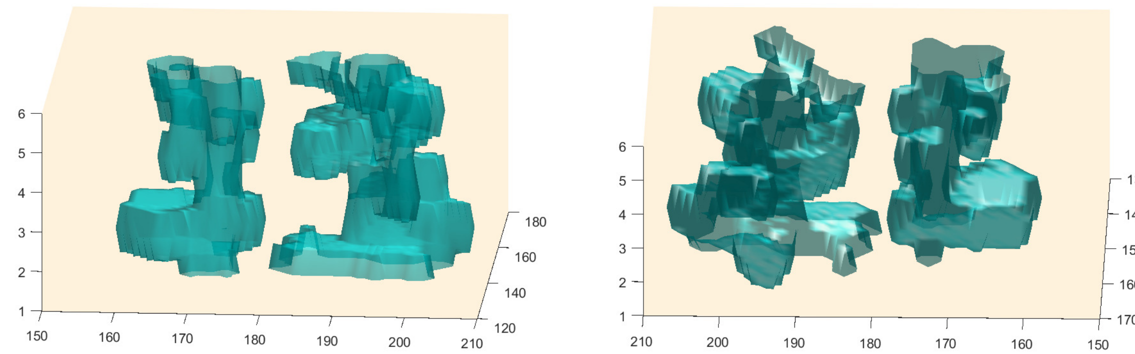


Figure 4.14: 3D reconstruction of Transitional zone. The transitional zone is divided into two parts. The shape is quite random but we believe more accurate 3D reconstruction can be done by good quality dataset.

The 3D reconstruction of Tumor is shown in below figure.

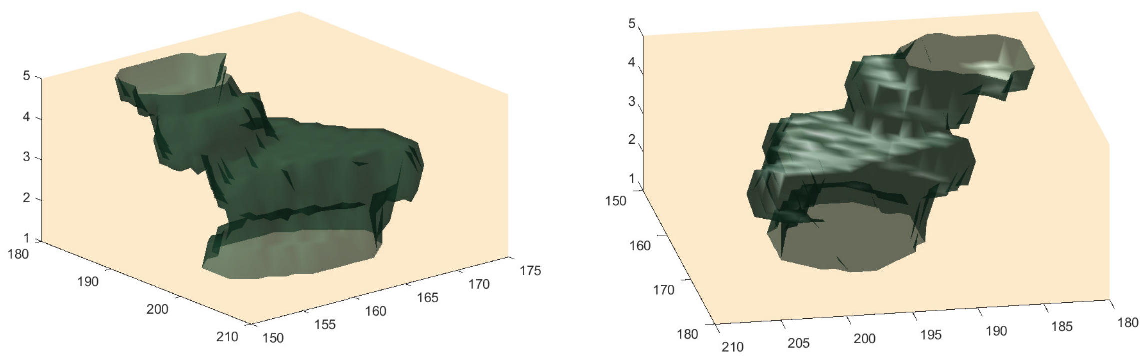


Figure 4.15: 3D reconstruction of tumur (cancer). The tumur has totally rando shape and is usually relatively small.

Executive Summary

Prostate cancer can be detected successfully with Active contour model or snake algorithm. The 3D reconstruction might not be the most precise and accurate but gives us a good estimate and idea of behaviour of tumur and well as anatomy of prostate. We create a MATLAB app and execution file to implement it. The MATLAB app can be installed on MATLAB and used to demonstrate to future students. This was a wonderful oppertunity to learn and implement Active contour model. We found it to be extremely powerful and great tool for segmentation. We realized that its applications can be endless. We are really thankful to Mr. Christian MATA for his guidance. We also acknowledge Github, MATLAB online platform and Stack overflow for their support and helping us with coding queries.

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