

**ÇUKUROVA UNIVERSITY
INSTITUTE OF NATURAL AND APPLIED SCIENCES**

MSc THESIS

Devrim KAYALI

**DETECTION AND 3D MODELING OF BRAIN TUMORS
USING IMAGE SEGMENTATION METHODS AND VOLUME
RENDERING TECHNIQUES**

**DEPARTMENT OF ELECTRICAL AND ELECTRONICS
ENGINEERING**

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We certify that the thesis titled above was reviewed and approved for the award of degree of the Master of Science by the board of jury on 07/01/2020.

.....
Prof. Dr. Ulus ÇEVİK
SUPERVISOR

.....
Prof. Dr. Mustafa GÖK
MEMBER

.....
Asst. Prof. Dr. Gökay
DİŞKEN
MEMBER

This MSc Thesis is written at the Department of Electrical and Electronics Engineering of Institute of Natural And Applied Sciences of Çukurova University.

Registration Number:

**Prof. Dr. Mustafa GÖK
Director
Institute of Natural and Applied Sciences**

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ABSTRACT

MSc THESIS

DETECTION AND 3D MODELING OF BRAIN TUMORS USING IMAGE SEGMENTATION METHODS AND VOLUME RENDERING TECHNIQUES

Devrim KAYALI

ÇUKUROVA UNIVERSITY
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: Prof. Dr. Mustafa GÖK

: Asst. Prof. Dr. Gökay DİŞKEN

The abnormal and uncontrollable growth of cells inside the brain is called a brain tumor. Brain tumors are graded from the first degree to the fourth degree, from low to high depending on the risk they carry. Therefore, the sooner the tumor is detected and intervened, the more successful the treatment will be. Because the damaged brain tissue and its functional disorders are difficult to recover, it is important to detect the tumor early and remove it before a further spread. However, there is a risk of damaging healthy tissues during this operation. However, if you have more information about the tumor's location, size and how it spreads inside the brain, the success rate of the operation will be greatly increased and the risk will be minimized.

Magnetic Resonance Imaging (MRI) is the most effective imaging method for the detection of the brain tumor. MRI images consist of 2D slices. With these images, the tumor can be detected, but no precise information about its shape and spread can be obtained from individual slices. However, it is possible to obtain more information by processing the MRI images. A 3D image can be obtained from 2D slices with volume rendering, but to obtain a 3D image of the brain tumor, first tumor tissue must be separated from the normal brain tissues using image segmentation algorithms. After a successful image segmentation, the 3D image can be obtained using volume rendering on processed images.

In this thesis, with the developed software, MRI images are taken as input and they are automatically processed. After the process is finished and the detection is completed the 3D shape of the detected tumor is re-created and its features can be observed.

Keywords: tumor, mri, image segmentation, volume rendering.

ÖZ

YÜKSEK LİSANS TEZİ

GÖRÜNTÜ SEGMENTASYON YÖNTEMLERİ VE HACİM OLUŞTURMA TEKNİKLERİ KULLANILARAK BEYİN TÜMÖRLERİNİN SAPTANMASI VE 3 BOYUTLU MODELLENMESİ

Devrim KAYALI

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Beyin içindeki hücrelerin anormal ve kontrolsüz büyümesine beyin tümörü denir. Beyin tümörleri taşıdıkları riske göre düşükten yükseğe doğru olmak üzere birinci dereceden, dördüncü dereceye kadar derecelendirilir. Bu nedenle tümör ne kadar erken tespit edilip müdahale edilirse tedavi de o kadar başarılı olur. Hasarlı beyin dokusu ve fonksiyonel bozukluklarının iyileşmesi zor olduğundan, tümörü erken tespit etmek ve daha fazla yayılmadan önce almak önemlidir. Ancak, bu işlem sırasında sağlıklı dokulara zarar verme riski vardır. Bu nedenle, tümörün yeri, büyüklüğü ve beynin içinde nasıl yayıldığı hakkında daha fazla bilgi sahibi olunur ise, operasyonun başarı oranı büyük ölçüde artacak ve risk en aza indirilecektir.

Manyetik Rezonans Görüntüleme (MR), beyin tümörünün tespiti için en etkili görüntüleme yöntemidir. MR görüntüleri 2D kesitlerde oluşmaktadır. Bu görüntülerle, tümör tespit edilebilir, ancak tek bir kesit görüntüsünden şekli ve yayılması hakkında kesin bir bilgi elde edilemez. Bununla birlikte, MRI görüntülerini işleyerek daha fazla bilgi edinmek mümkündür. Hacimsel Gösterim yöntemleri ile 2D kesitlerden 3D görüntü elde edilebilir, ancak amaç beyin tümörünün 3D görüntüsünü elde etmek olduğunda, hacimsel gösterim yöntemleri kullanmadan önce görüntü segmentasyonu algoritmaları kullanılarak tümörlü dokular normal beyin dokularından ayrılmalıdır. Görüntü segmentasyonu başarı ile yapıldıktan sonra hacimsel gösterim kullanılarak 3D görüntüye ulaşılabilir.

Bu tezde geliştirilen yazılım ile MR görüntüleri girdi olarak alınmakta ve otomatik olarak işlenmektedir. İşlemler bittikten ve tespit tamamlandıktan sonra, tespit edilen tümörün 3D şekli yeniden oluşturulur ve özellikleri gözlenebilir.

Anahtar Kelimeler: Tümör, MR, Görüntü Segmentasyonu, Hacimsel Gösterim.

EXTENDED ABSTRACT

A brain tumor is an uncontrollable and abnormal growth of the cells inside the brain. Depending on the risk they carry they are graded from first to fourth grade. Brain tumors are called malignant if they are cancerous. Cancerous brain tumors are aggressive, and they grow rapidly inside the head. They can also spread to other tissues, and other parts of the body. They are called benign if they are not cancerous, and they grow slowly.

There are different imaging techniques used in medical imaging for different purposes, such as diagnosis, treatment or routine controls, and checkups. MRI images are used to detect brain tumors. Because it visualizes the internal structure of the body in great detail, and it is a non-invasive imaging tool. Also, there is no exposure to ionizing radiation, like in CT imaging.

There are many different studies about brain tumors that use different methods for tumor detection, tumor size calculation, and remodeling. These methods may include artificial neural networks (ANN) or can be algorithm based, and do not include ANN.

Volume rendering is used to obtain 3D models from 2D images. Screens are two dimensional, and consist of pixels. Voxels are used instead of pixels to represent a volume. Volume visualization is important in medical imaging because it gives more information from the images acquired from the scanners, such as CT or MRI.

In this thesis, 2D MRI slices from different patients were used during development. A research on image segmentation, and volume rendering was carried out to learn about the algorithms, and techniques. After the research, different combinations of image segmentation algorithms were tried on the datasets to achieve an accurate detection. Images go through several different processes to achieve this accurate detection. Just a single detection process is not enough since the human brain has a complex structure. Brain tumor operations are risky, and

may cause in permanent harm to the patient if the operation does not go well, which means inaccurate detections are not acceptable. So, image segmentation was conducted in 4 stages: Noise Reduction, Image Enhancement, Tumor Detection, and Fixing Possible Errors.

Noise Reduction is very important since getting rid of any kind of noises increases the success rate in any kind of process. Image Enhancement is used to enhance and simplify the image to prepare it for the detection phase. Histogram equalization is one of the image enhancement methods which makes enhancement to the pixels according to the histogram of the image. It results in an image with higher contrast.

Detection phase is conducted on the image with a radius-based manner. Fixing Possible Errors phase solves the problems which may occur at the detection phase. These are the problems which are caused by the radius based detection, and the intensity value of some normal brain tissues since they may sometimes have the intensity value for being a tumor. These two problems do not have an efficient solution when the slices are taken individually, which means in 2D. But in 3D, there is a simple solution, continuity. Brain tumor starts from a point inside the head, and then spreads, which means it is a 3D object, and it has to be continuous over the 2D slices.

The detection process is not just about detecting tumors from the input image, in that way accuracy would be very low. The process takes an input image, and by applying several algorithms, prepares the image for itself before detection to obtain accurate detection. Nevertheless, detection can still face some problems. To overcome these problems, after applying the detection algorithm to all of the slices, the whole set of slices are taken, and checked if they satisfy continuity in 3D.

After obtaining an accurate combination of algorithms, volume rendering was applied to obtain the 3D model. There must be a predefined camera position in the space to render the 2D projection of a 3D data set. Also, the opacity, and color

of every voxel must be defined. An RGBA (red, green, blue, alpha) transfer function is used to define the RGBA value for voxels which define their opacity, and color. In this transfer function R, G, B values define the color, and A value defines the opacity.

In order to add lighting, and see how the obtained object looks in a 3D light scene, the surface normal estimation must be done. Because voxels obtained from the pixels do not have a normal value, they will end up in complete darkness in an illuminated scene. This means that a surface normal for every voxel has to be calculated. Surface normals of the voxels are calculated by examining the existence of the 26-connected neighborhood voxels. Voxels react according to the light after they have normal value information. But further calculations must be done to increase the quality of the rendered object, because the image is still not realistic even after calculating the surface normals. The image may have a smoothness problem because of the gaps between 2D slices. To get rid of this problem which is called the staircase effect, surface smoothing is done. Surface smoothing is done by using the 26-connected neighborhood voxels again. After these calculations, the staircase effect is eliminated, and the image becomes smoother.

An option was added to the software to render both tumor detections, and any type of 2D slice datasets, such as CT or MRI without any process. This objective was completed by using the CT HEAD dataset because it is hard to understand the success rate with the tumor detections since they have unpredictable random shapes. Obtaining a realistic 3D image from the CT dataset means high-quality rendering is accomplished, and the software is ready for the 3D rendering of the detected tumors.

A user interface was designed, and improved using C#, and OpenGL coding to combine detection and volume rendering, and some tools were added to the software so the inspection can be done better.

By using the developed software, detections on 5 different datasets were done, and the 3D models of them were obtained. 256 slices from these 5 different

datasets were processed, and 99 detections were made. In 1 of the slices, the tumor was totally missed. In 3 slices there was detection but a small part of it was missed. In 7 slices, there were extra filled tumor parts which caused a little noisy 3D image. There was no wrong detection. Also, 3D models of two different Headneck Cetuximab datasets were rendered to make sure that the software gives realistic outputs on different datasets.

In medical imaging, the final processed image quality is very important since it must give accurate and realistic results to provide information for diagnosis. The output image quality was perceptually satisfying even for low-resolution images of the tumors. The realistic output image obtained from the CT HEAD dataset proves that the volume rendering algorithm works efficiently, and the output images of the tumors look realistic.

Use of the developed software may save time, and reduce human workload. More information can be obtained out of 2D slices in a short time, and if there is an operation that needs to be done, visualization of what is going to deal with can be seen. This means better preparation for the operation, which will greatly increase the success rate of it.

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ABBREVIATIONS

2D	:	Two Dimensional
3D	:	Three Dimensional
ANN	:	Artificial Neural Network
C#	:	C Sharp (Microsoft programming language)
CNS	:	Central Nervous System
CT	:	Computed Tomography
FLAIR	:	Fluid-Attenuated Inversion Recovery
MRI	:	Magnetic Resonance Imaging
OPENGL	:	Open Graphics Library
RGB	:	Red,Green,Blue
RGBA	:	Red,Green,Blue,Alpha
TCIA	:	The Cancer Imaging Archive



1. INTRODUCTION

1.1. Overview

By using powerful computers, it is possible to run many complex algorithms and obtain high-quality 3D renderings with the processing unit and graphical unit inside them. Personal computers in today's technology have the power to achieve these. This means either the development and the usage of the software is possible in personal use. With this opportunity, software, like developed in this thesis can reduce the workload and provide information in a short time.

1.2. Brain tumors

As mentioned before uncontrollable growth of cells inside the brain is called a brain tumor. They are classified as malignant or benign whether they include cancer cells or not. If tumors include cancer cells, they are called malignant and these cells are aggressive. These tumors grow rapidly inside the head and can also spread to other tissues and other parts of the body. The tumor is called benign if there are no cancer cells, which does not spread to nearby tissues (Angulakshmi and Priya, 2018). There are over 120 brain and central nervous system (CNS) tumor types that are different for everyone. They develop from different cell types in different areas and may have different treatment options (Sudharani, et al., 2016).

1.3. Image modalities

Medical imaging is very important in medicine because it gives the chance to visualize the human body for different purposes such as diagnosis, treatment or routine controls and checkups. Different types of modalities are used for these purposes, such as X-RAY, Computed Tomography (CT), Magnetic Resonance Imaging (MRI) and Ultrasound Imaging.

X-RAY imaging is done by sending X-RAYS to the desired body part and obtaining an image with different intensity values which determine different tissues. These intensity values are caused by the different radiation absorption amounts of each tissue. Besides imaging, X-RAY is also used in treatment which is called radiotherapy. High energy X-RAY beams are used for treating cancer (Hill, et al., 2014). Since X-RAYS have an ionizing effect on cells, they may be harmful especially for the pregnant.

Computed Tomography is the use of many X-RAY beam combinations taken from different angles and processed on a computer which creates slice images of the object which allows seeing inside of it. It was developed by Allan M. Cormack and Godfrey N. Hounsfield in 1979 and they won the Nobel Prize in Physiology or Medicine ("The Nobel Prize in Physiology or Medicine 1979").

Ultrasound imaging is done by sending ultrasound to the body and displaying the reflection as an image. Ultrasound means sound waves that are at a high frequency that can not be heard by humans, so they are safe to use since there is no ionizing radiation. Different tissue types cause different reflection, so by continuously sending ultrasound and processing the reflection, real-time ultrasound imaging is obtained (Hides, et al., 1998).

But when analyzing the internal structure of the body like the brain, MRI is the most efficient method for the detection of the brain tumor. Because it is a non-invasive imaging tool that utilizes a strong magnetic field and radiofrequency waves to visualize in great detail organs, soft tissue, and bone. Also, there is no exposure to ionizing radiation, so it is considered safe for nearly every age group at field strengths below 7 Tesla (Nelson, 2008). This harmless procedure also gives good resolution and these advantages altogether make MRI an excellent choice for the detection of the brain tumors.

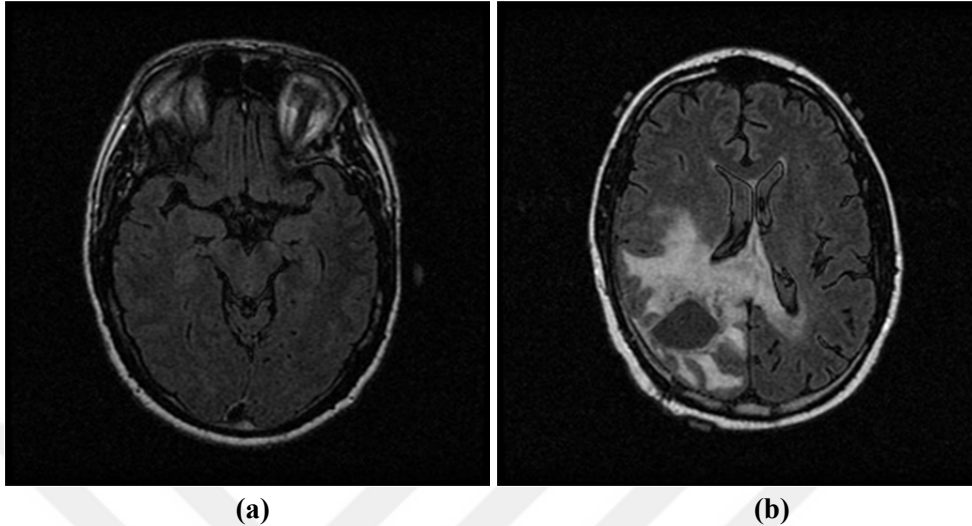


Figure 1.1. An MRI Slice **a.** without tumor. **b.** with tumor. Tumor Detection Algorithms

1.4. Tumor Detection Algorithms

There are many different studies about brain tumors that use different methods for tumor detection, tumor size calculation, and remodeling. These methods can include artificial neural networks (ANN) or can be algorithm based and do not include ANN.

Morphological examination by structure and shape was one of the first methods for tumor detection (Gibbs, et al., 1996). The robust estimation method is another method in which both edema and tumor were detected with geometric shape abnormalities and pixel density (Prastawa, et al, 2003). Later on, an important technique called edge detection was used in studies (Kumar, 2011), (Ananda and Thomas, 2012) and (Banerjee, 2015) for marking the tumor area in the MRI images. Edge detection is also widely used in image processing for finding object boundaries by looking for discontinuities in brightness. After achieving a good accuracy at tumor detection and marking the tumor area in the studies, volume calculations were also done. If slice thickness and pixel spacing

attributes are known, the volume of the tumor can be calculated by using all of the MRI slices.

In one of the studies performed in 3D, a region growing technique was applied for detecting the tumor. Then the tumor was imaged using volume rendering, and the surface area and volume of the tumor were also calculated (Sudharani, et al., 2016). In (Mitra, et al., 2017) FLAIR, T1C, and T2, which are different types of MRI images, were used together instead of using just one type of MRI image. A 3D image of the tumor was obtained by assigning the color values of these 3 different types of images to R, G, B values and, using them at the same time.

To increase the success of tumor detection, besides the improvements made in the image processing phase, preprocessing can be done to the images as in (Isselmou, el al., 2016), (Kanmani and Pushparani, 2016) and (Toum, et al., 2017). Algorithms such as median filter, histogram equalization, thresholding are very important because applying them at the preprocess stage greatly increases the success rate at the image processing phase.

1.5. Volume Rendering

Volume visualization started in the 1980s with the need of getting more information from the data acquired from magnetic resonance imaging (MRI) and computed tomography (CT) scanners (Callahan, et al., 2008). Techniques used in scientific visualization and computer graphics to display the 2D projection of a 3D scalar field is called Volume Rendering. With the help of powerful computers, volume rendering is not limited to medical applications. It is also used in engineering, science, and computer games.

Screens we use consist of pixels, which are two dimensional. Volume rendering is used to show three-dimensional data in two-dimensional screens. Voxels are used instead of pixels, while pixels represent the unit area voxels represent a unit volume (Çelebi, 2003).

There must be a defined camera position in the space to render the 2D projection of a 3D data set. Also, the opacity and color of every voxel must be defined. An RGBA (red, green, blue, alpha) transfer function is used to define the RGBA value for voxels which defines their opacity and color. In this transfer function R, G, B values define the color and A value defines the opacity.

Volume visualization algorithms are classified as Indirect Volume Rendering (Surface Rendering) and Direct Volume Rendering (Volume Rendering). Indirect Volume Rendering algorithms use geometric primitives to visualize the volume while Direct Volume Rendering algorithms render each voxel directly without using any geometric primitives (Çelebi, 2003). Volume ray casting is a direct volume rendering method that uses image order for rendering which provides very high-quality results. In this technique, a ray is generated for each pixel using a camera model. The ray starts at the center of the projection of the camera and passes through the image pixel on the imaginary image plane floating in between the camera and the volume to be rendered. Then the ray is sampled at regular or adaptive intervals throughout the volume. The process is repeated for every pixel on the screen to form the completed image.

1.6. Conclusion

Research about tumors and medical imaging was done to get information about the brain tumors and the methods used to detect them. Different image segmentation algorithms were investigated and volume rendering techniques were studied to get the highest quality results.



2. TUMOR DETECTION

2.1. Introduction

In this thesis, our task is to highlight the tumor area of images taken from MRI devices, and to extract the tumor to display it and make some measurements on it, such as, volume and size.

Datasets (MRI images) taken from The Cancer Imaging Archive website were used ("The Cancer Imaging Archive (TCIA) -"). These are 2D FLAIR MRI slices of a couple of different patients. MRI slices of a patient are seen in Figure 2.1.

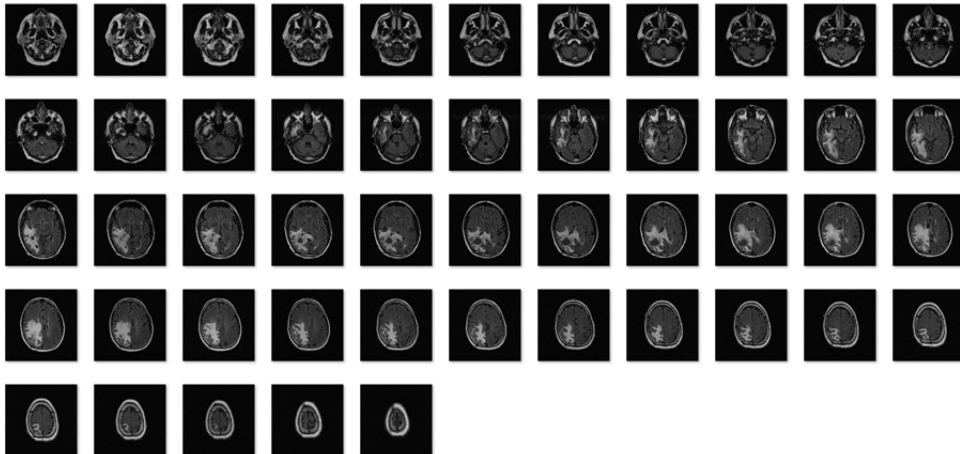


Figure 2.1. MRI Slices of a Patient

2.2. Detection Phases

Taken images go through several different processes to achieve an accurate detection. Just a single detection process is not enough since the human brain has a complex structure. Brain tumor operations are risky and have a chance to cause permanent harm to the patient if the operation does not go well, which means inaccurate detections are not acceptable. Detection phases consist of 4 stages; Noise Reduction, Image Enhancement, Tumor Detection, Fixing Possible errors.

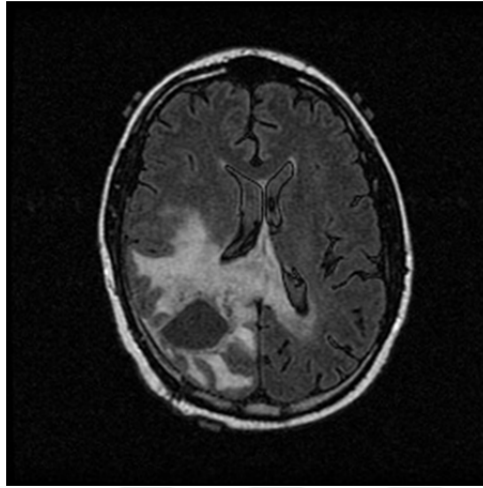


Figure 2.2. An Original MRI image with tumor

2.2.1. Noise Reduction

Noise reduction is the first stage of the detection process. It is very important to get rid of any kind of noise in any kind of operation as much as possible before the process because they will decrease the success rate and cause increased time in calculations. Simply they are unwanted data and there is no needed information in them.

To get rid of noise in MRI images “Air to Surface Threshold” is applied. This means clearing pixels with intensity values lower than a predetermined threshold value, which results in a clear MRI image just having the information needed.

In Figure 2.3 noises are indicated with the red pixels which are called salt and pepper noise. All the noises indicated with red are cleared at this stage and Figure 2.4 is obtained. It is clearly seen that getting rid of those pixels did not cause any information loss but this will save time in further processes.

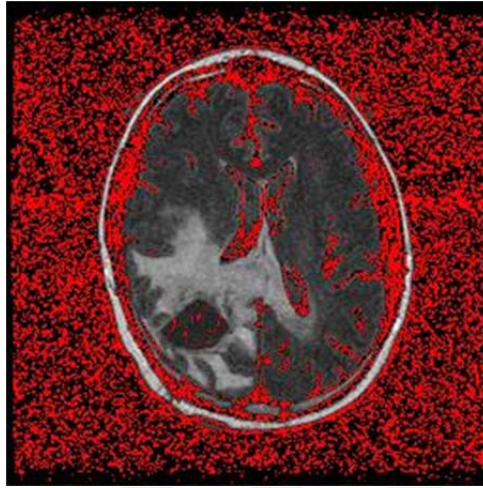


Figure 2.3. Salt and pepper noise

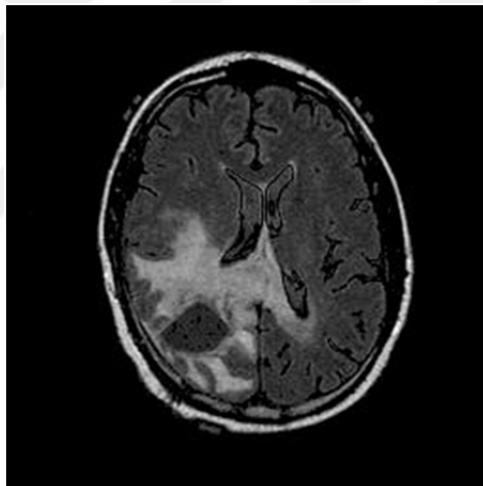


Figure 2.4. Threshold applied image without salt and pepper noise

2.2.2. Image Enhancement

Some image enhancement steps are used after noise reduction to obtain a better image before the tumor detection phase. The human brain has a complex structure and sometimes it can be challenging to separate other tissues from normal brain tissues. This means getting an image as simplified as possible increases the

success rate of the detection. To achieve this, Histogram Equalization, Thresholding and Filtering are used respectively.

A histogram is a graph, showing the numbers of color values in an image. Applying histogram equalization enhances the pixels, according to the histogram of the image (Russ, 2002). This provides an image with a higher contrast. Histogram equalization also minimizes the contrast difference between slices. The tumor becomes more obvious after the histogram equalization but the normal tissue is also enhanced. To get rid of them, thresholding is applied. Thresholding is the display of only the desired color value range in the image and, as seen in Figure 2.7, most of the normal brain tissue is cleared by using this method.

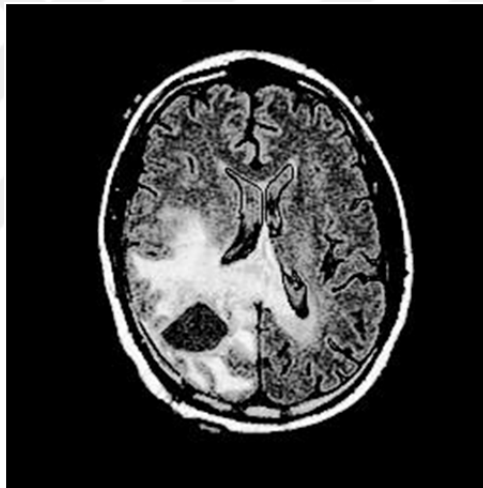


Figure 2.5. Histogram equalized image

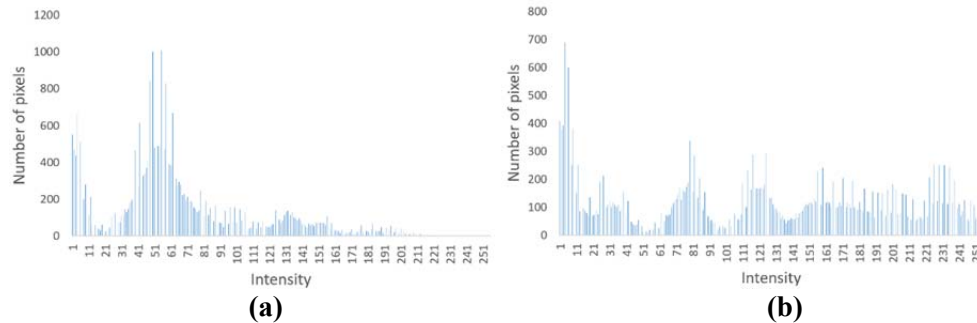


Figure 2.6. Histogram a. before histogram equalization and b. after histogram equalization.

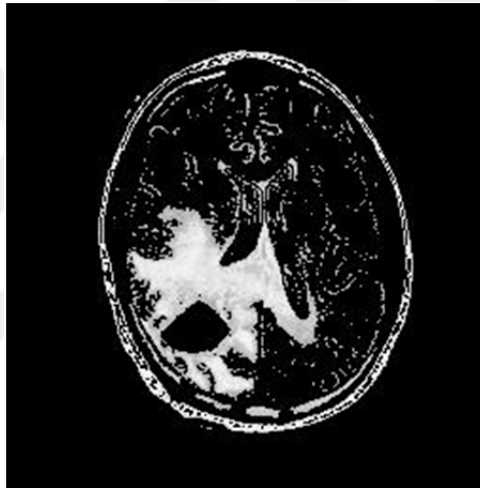


Figure 2.7. Threshold applied image

At this stage, most of the normal brain tissues are cleared from the image as mentioned. The image has become simpler and the tumor can be easily detected by eyes. But one more process is done to obtain the simplest image possible before the detection phase. This step which is called additional filtering gets rid of more pixels that are not part of the tumor. The decision for this is made by looking around every pixel if they are part of a bigger object and if it is not, deleted. By getting rid of every pixel that is certainly not part of the tumor, the image is ready for the detection phase (Figure 2.8).

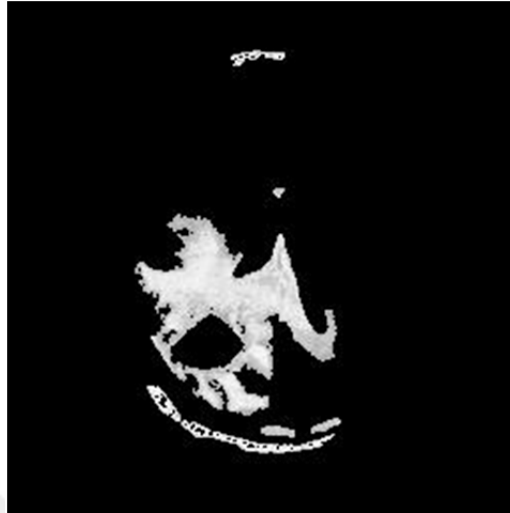


Figure 2.8. An Additional filtered image

2.2.3. Tumor Detection

Since the image goes through several preprocess stages to get simplified as much as possible, using a radius-based detection at the detection phase easily detects the tumor. A certain radius around every pixel is checked and marked if full. Then the whole tumor is filled using the marked pixels. When the whole tumor is filled, just the tumor is left in the image and all the other pixels are eliminated. Figure 2.9, Figure 2.10, and Figure 2.11 show these steps respectively.

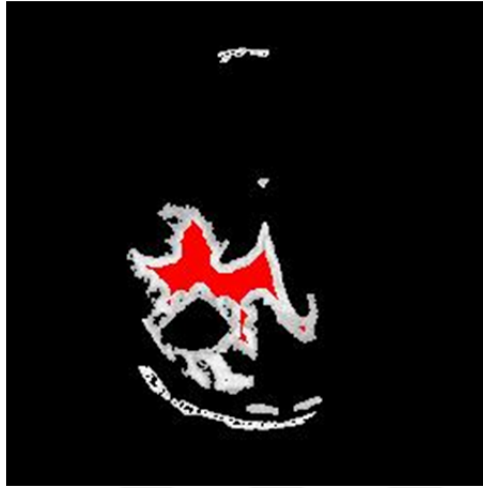


Figure 2.9. Radius-based detected pixels by the algorithm



Figure 2.10. Filled detection



Figure 2.11. The final image of the tumor.

2.2.4. Fixing Possible Errors

At the development stage, the detection algorithm faced two common errors. One of them is the detection error because of the radius-based detection algorithm, and the other one is the incorrect marking and filling of the normal brain tissue since they can sometimes satisfy the intensity and radius criteria of the algorithm for being a tumor. These two problems do not have an efficient solution when the slices are taken individually, which means in 2D. But in 3D there is a simple solution, continuity. Brain tumor starts from a point inside the head and then spreads, which means it is a 3D object and it has to be continuous over the 2D slices.

Since the detection is radius based, it can miss the small parts of the tumor in some of the slices (Figure 2.12). To solve this problem, similarity to the detection of the previous slice is compared and if there is a tumor part it is filled (Figure 2.13).

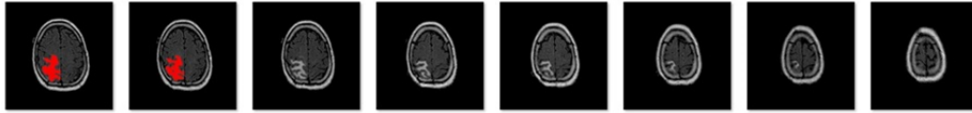


Figure 2.12. Radius error

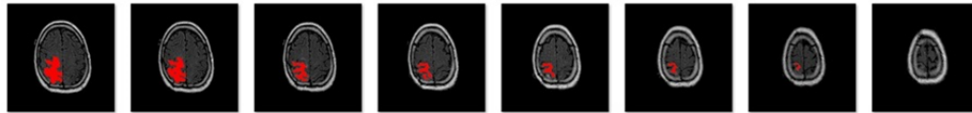


Figure 2.13. Radius error fixed

The other problem of the tumor detection algorithm which can mark normal brain parts as a tumor is solved by checking the slices for continuity. A brain tumor is a whole thing so if a slice has detection and it is not continuous over other slices, detection is canceled.

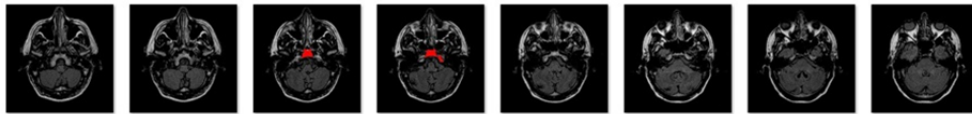


Figure 2.14. Detection error

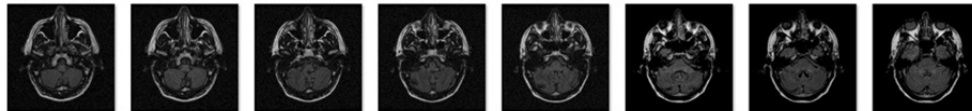


Figure 2.15. Detection error fixed

2.3. Conclusion

The detection process is not just about detecting tumors from the input image, in that way accuracy would be very low. The process takes an input image and by applying several algorithms, prepares the image for itself before detection to obtain accurate detection. Figure 2.16 shows the block diagram of the whole detection process for a single MRI slice and Figure 2.17 shows an output image. Nevertheless, detection can still face some problems. To overcome these problems,

after applying the detection algorithm to all of the slices, the whole set of slices are taken and checked if they satisfy continuity in 3D.



Figure 2.16. Block Diagram of the detection process

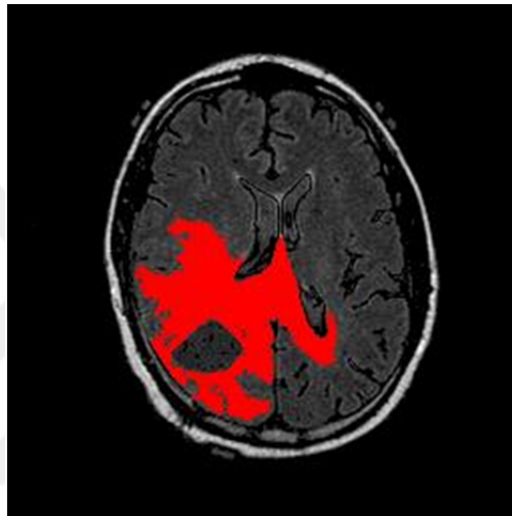


Figure 2.17. Tumor Detection Output

3. RENDERING

3.1. Introduction

This chapter is about how the rendering process is implemented in the software. Rendering is not limited to tumor detected images, the software has options to render usual medical imaging slices under desired conditions which will be explained in the next chapter.

The rendering process will be explained with a CT HEAD dataset because tumors spread randomly inside the brain and their resolution is low, so it can not be verified that the 3D model is realistic. To make sure that 3D models of the tumors are realistic, a realistic output from the CT HEAD dataset was acquired.

3.2. Volume Rendering

Once the image segmentation has been accomplished for all of the slices, volume rendering is used to obtain the 3D model of the detected brain tumor. The 3D image is obtained by combining 2D MRI images that went through the image segmentation algorithms. At this stage, the raw data from the slices are rendered using voxels with the intensity values of corresponding pixels (Figure 3.1).

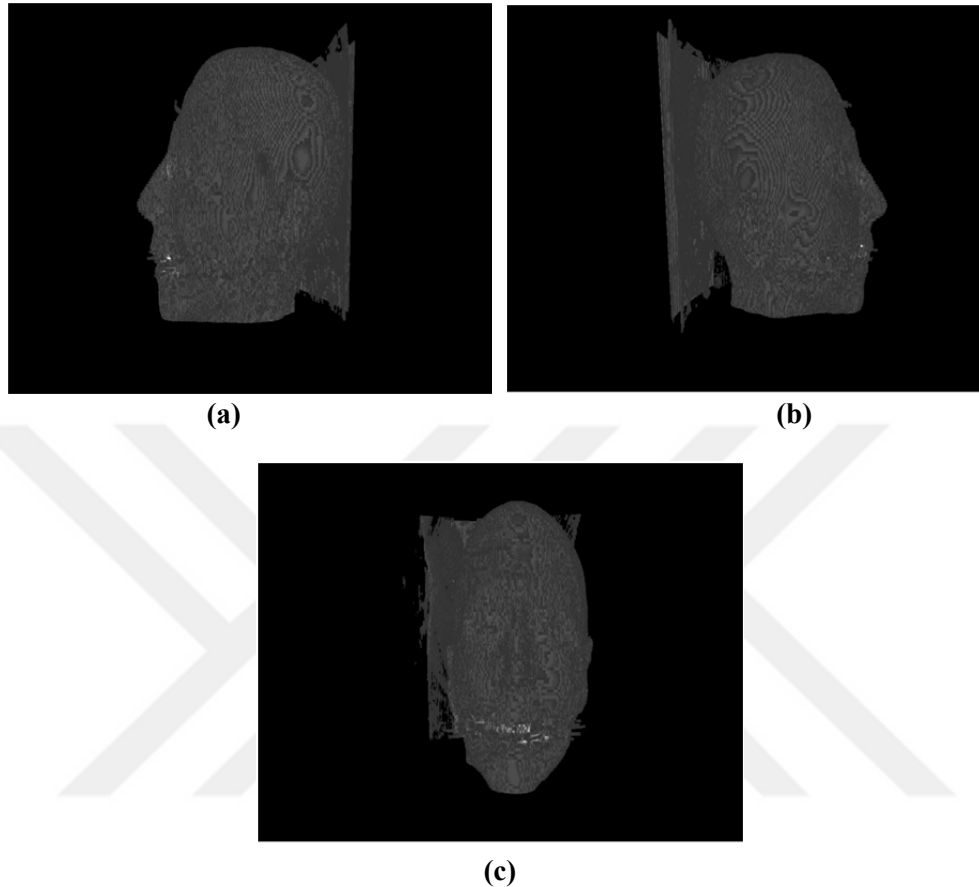


Figure 3.1. 3D Rendered image of CT dataset. a. Sagittal, b. Sagittal, and c. Frontal

3.3. Surface Normal Estimation

In order to add lighting and see how the obtained object looks in a 3D light scene, the surface normal estimation must be done. Because voxels obtained from the pixels do not have a normal value, they will end up in complete darkness in an illuminated scene. This means surface normal for every voxel has to be calculated. Surface normals of the voxels are calculated by examining the neighborhood voxels. Since the examination is done in 3D, it is called the voxel-space surface normal estimation method [17]. By examining the existence of 26-connected neighborhood voxels seen in Figure 3.2, the surface normal for every voxel is

individually defined. Voxels react according to the light after they have normal value information. After all surface normals are calculated, an illuminated scene can be formed by shedding lights in the space. The obtained 3D model at this stage is seen in Figure 3.3. Although a 3D object is obtained, it has some problems and it is not realistic. Further calculations must be done to increase the quality of the rendered object.

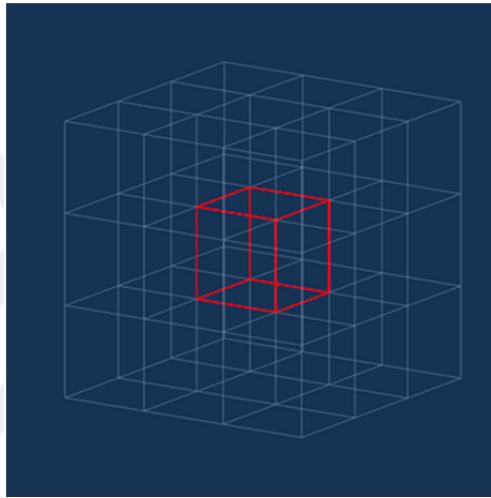


Figure 3.2. 26-Connected Neighborhood Voxels

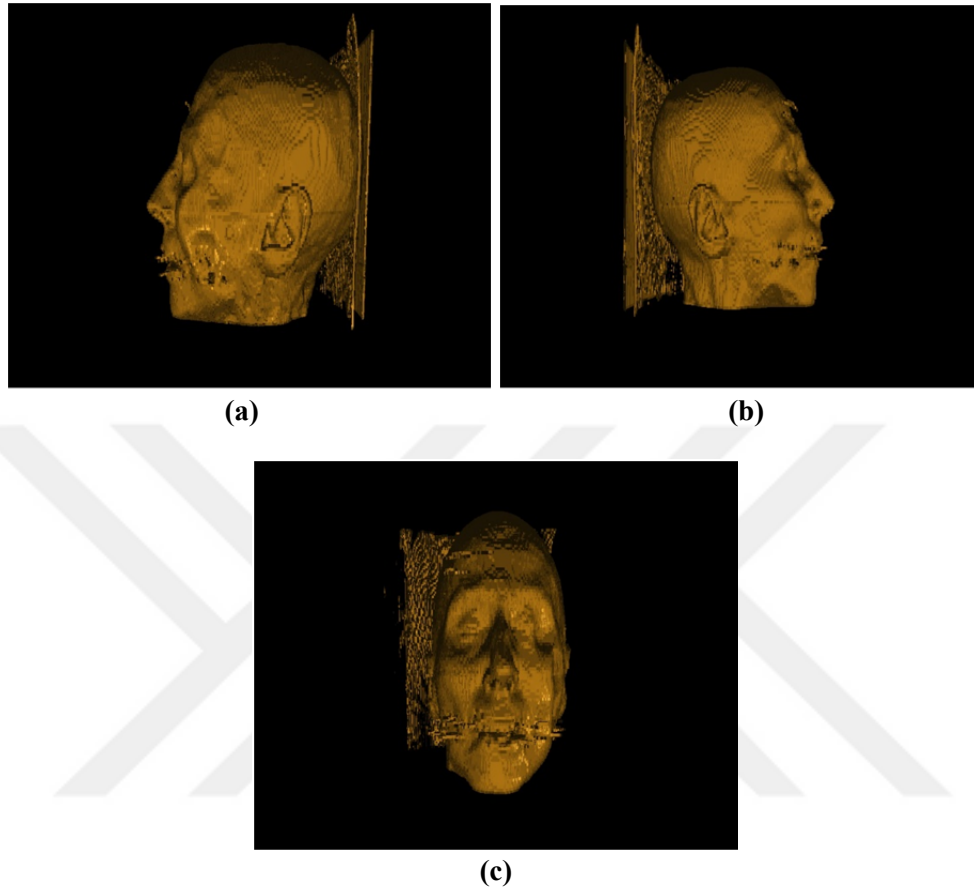


Figure 3.3. 3D Rendered image of CT dataset after surface normal estimation.
a. Sagittal, b. Sagittal, and c. Frontal

3.4. Surface Smoothing

As seen in Figure 3.3 the image is still not realistic even after calculating the surface normals. The image has a smoothness problem because of the gap between 2D slices. Slices are recorded at intervals, so they are not continuous. This discrete sampling causes a problem called the staircase effect [17]. To get rid of this problem surface smoothing is done.

In the developed software surface smoothing is done by using the 26-connected neighborhood voxels again. First, 26-connected neighborhood voxels are checked to see which ones exist, and existing voxels with non-zero surface normal

values are taken and averaged with the surface normal value of the current voxel. Also, to preserve the edges, the angle between the current surface normal and the surrounding surface normal is compared to satisfy a threshold angle. After these calculations, the staircase effect is gone and the image is smooth (Figure 3.4).

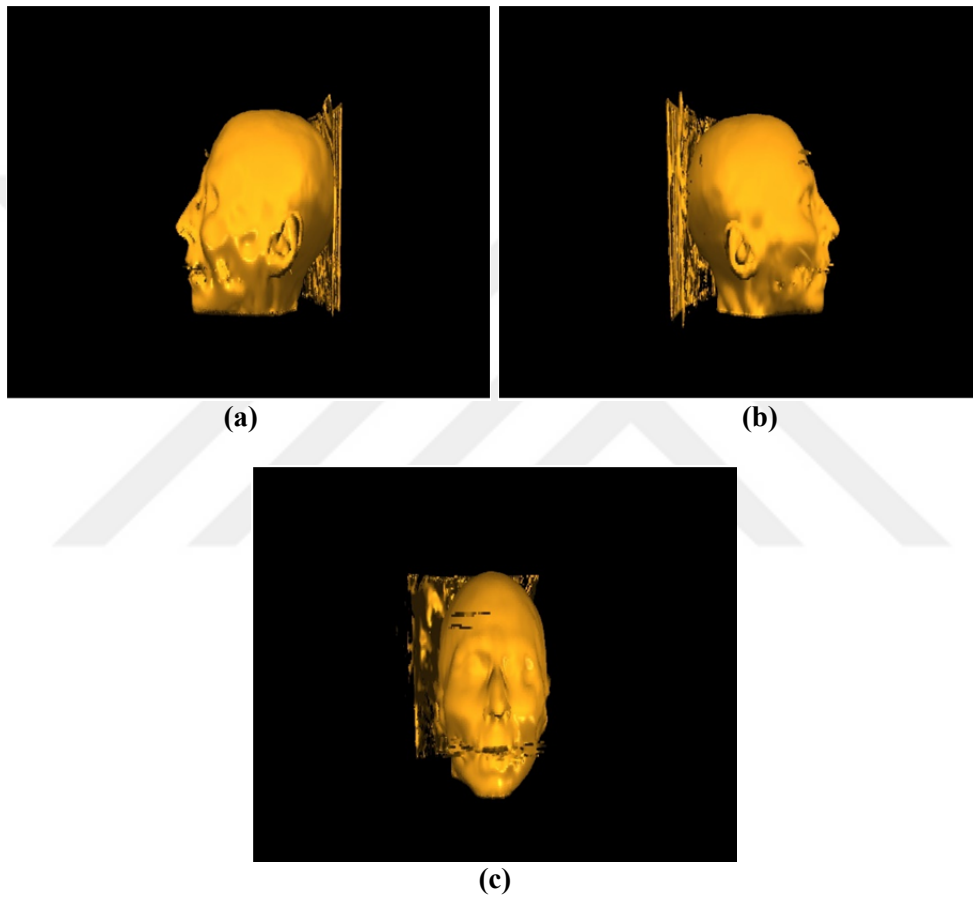


Figure 3.4. 3D Rendered image of CT dataset after surface smoothing. a. Sagittal, b. Sagittal, and c. Frontal

3.5. Conclusion

With surface smoothing, a realistic image is obtained with the CT dataset. Obtaining a realistic 3D image from the CT dataset means high-quality rendering is accomplished and the software is ready for the 3D rendering of the detected tumors.



4. SOFTWARE IMPLEMENTATION

4.1. Introduction

This chapter is about how the software is developed and how to use it to obtain results like displayed in this thesis. Some information about the software, tools included in the software and the walkthrough of the usage are given below.

4.2. Software Design

The software was designed using C#, and OpenGL coding. It consists of two main parts; the user interface at the left side of the screen and the graphical output screen at the right side of the screen (Figure 4.1).

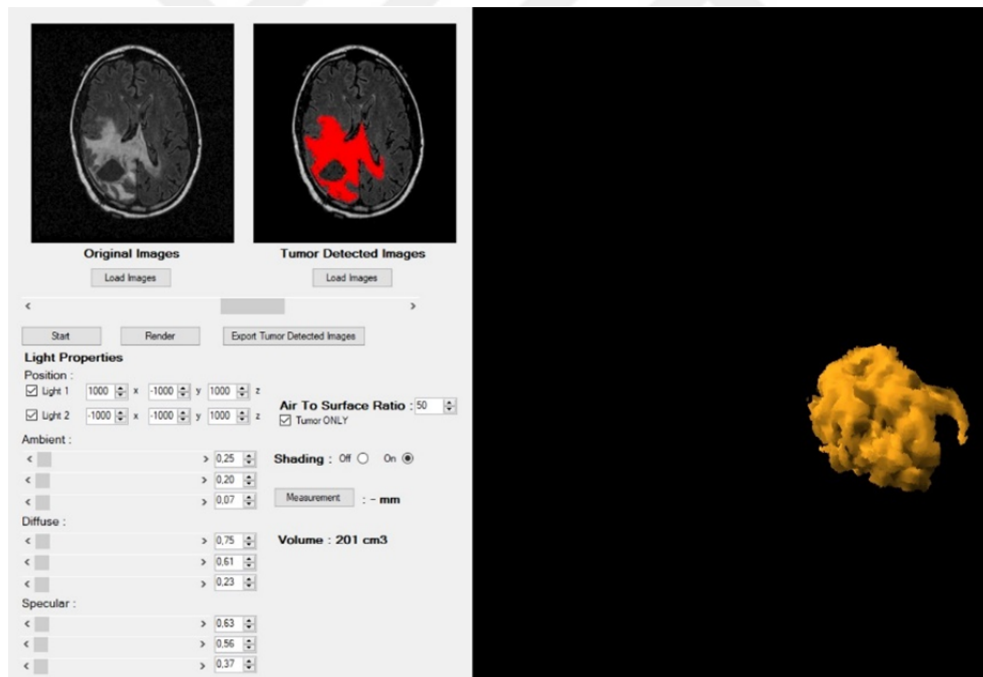


Figure 4.1. Screenshot of the developed software

“Load Images” button under the original images picture box is for uploading the images to the software. After uploading the images, there are 3 different options. If just rendering of the images is needed, the “Render” button is used while the “Tumor ONLY” checkbox is unchecked. Otherwise, no image will be obtained since there is no detection done. If detection needs to be done, “Start” button executes the tumor detection algorithm. 5 images in parallel are taken at a time to the process and rendering can be done after detection process for the whole dataset is finished. Detection process takes about 45 seconds for each slice, which means 5 images are processed every 45 seconds. Also, output images can be saved for later use with the “Export Tumor Detected Images” button. These images can be used later with the “Load Images” button under the tumor detected images picture box to directly do the rendering.

4.3. Software Tools

There are some tools can be used and parameters that can be changed in the software. Scrollbar under the picture boxes is for scrolling through the dataset and inspect the 2D images.

There are 2 different lights defined in the space. They can be turned on and off and their position (x,y,z) in the space can be defined individually as desired. Also Ambient (R, G, B), Diffuse (R, G, B), Specular (R, G, B) parameters of the lights can be changed.

Air to Surface Ratio can be defined to get rid of noises or to view just the desired parts. For example, viewing the skull in a CT image (Figure 4.2).

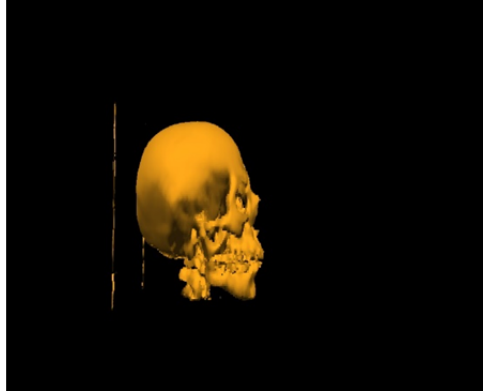


Figure 4.2. CT Head dataset thresholded

“Tumor ONLY” checkbox must be checked to view a tumor. When it is checked, only the detection which is marked as red will be rendered as it was mentioned before. Rendering while this checkbox is unchecked means rendering all of the pixels that satisfy the Air to Surface Ratio parameter.

Also, shading can be turned on and off. While shading is on the image is displayed realistic as the final high-quality image obtained which explained in Chapter 3. Turning shading off means viewing the image at its raw state with original intensity values (Figure 4.3).

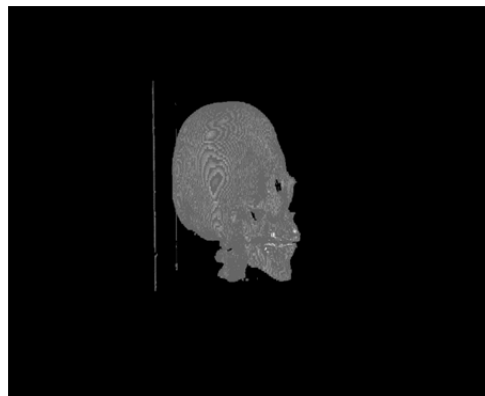


Figure 4.3. CT Head dataset thresholded and rendered shading off

A Measurement between two points can be done by clicking two points after clicking the “Measurement” button. This will display the distance between these two points. Also, the volume of the rendered object will be automatically displayed after the rendering process is completed.

The output image can be inspected using the translation, rotation, zoom in and zoom out features with left-click, right-click and scrolling when the cursor is on the output screen.

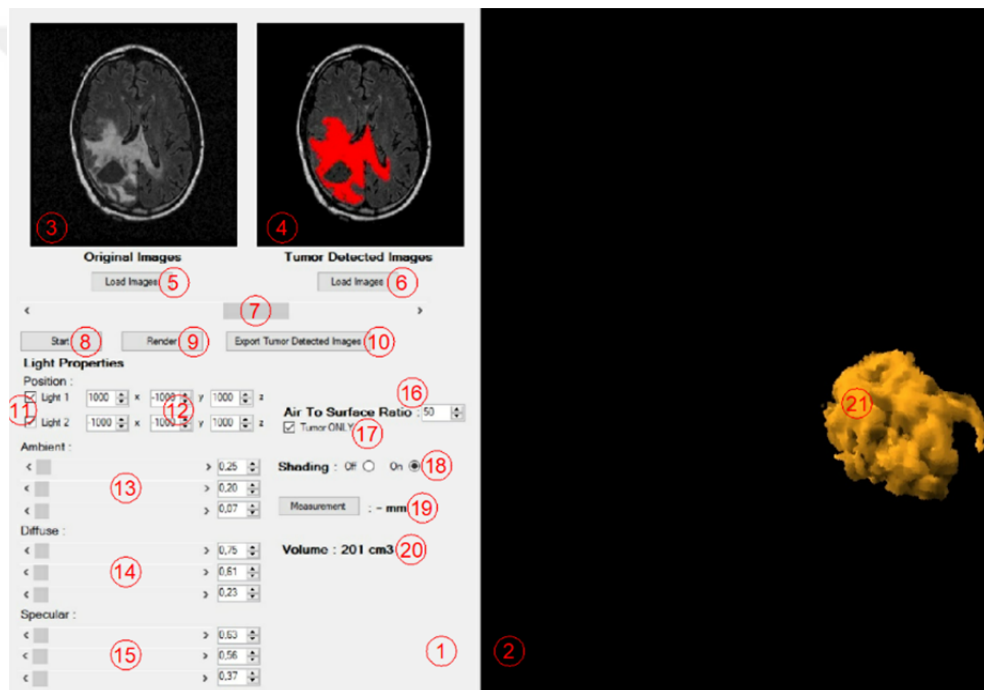


Figure 4.4. Numbered software sections.

Table 4.1. Description of the numbered sections.

NUMBER	DESCRIPTION
1	USER INTERFACE SCREEN
2	OUTPUT SCREEN
3	ORIGINAL IMAGES PICTUREBOX
4	TUMOR DETECTED IMAGES PICTUREBOX
5	BUTTON FOR UPLOADING RAW IMAGES
6	BUTTON FOR UPLOADING PRESAVED TUMOR DETECTED IMAGES
7	SCROLLBUTTON FOR SCROLLING THROUGH THE IMAGES IN THE PICTUREBOXES
8	BUTTON TO START THE DETECTION PROCESS
9	BUTTON TO START VOLUME RENDERING CALCULATIONS
10	BUTTON FOR SAVING THE TUMOR DETECTED IMAGES FOR LATER USE
11	CHECKBOXES TO TURN LIGHTS ON AND OFF IN THE SCENE
12	LIGHT POSITION PARAMETERS (x,y,z)
13	LIGHT AMBIENT PARAMETERS (R,G,B)
14	LIGHT DIFFUSE PARAMETERS (R,G,B)
15	LIGHT SPECULAR PARAMETERS (R,G,B)
16	AIR TO SURFACE RATIO PARAMETER
17	CHECKBOX TO TOGGLE BETWEEN NORMAL RENDERING AND TUMOR DETECTION RENDERING
18	RADIOBUTTONS TO TURN SHADING ON AND OFF
19	MEASUREMENT SECTION
20	VOLUME OF THE RENDERED OBJECT
21	RENDERED OBJECT

4.4. Conclusion

The software has a simple use that combines tumor detection and volume rendering. There is not any pop-up screen, so everything can be inspected on the same screen and changes on the parameters will take effect dynamically. Changes that require recalculation will not take effect instantly, because steps described in Chapter 3 has to be done again. For example, if air to surface ratio is changed, the structure of the object will be changed and because of this surface normals has to be calculated again.



5. RESULTS

This chapter shows the results obtained from the developed software. There are detections of 5 different datasets (Figure 5.3, Figure 5.5, Figure 5.7, Figure 5.9 and Figure 5.11) and rendered 3D images of their detections from 3 different views below (Figure 5.4, Figure 5.6, Figure 5.8, Figure 5.10, Figure 5.12). Also, some HEAD NECK datasets are rendered to visualize the quality of the rendering algorithm on different datasets (Figure 5.1 and Figure 5.2).

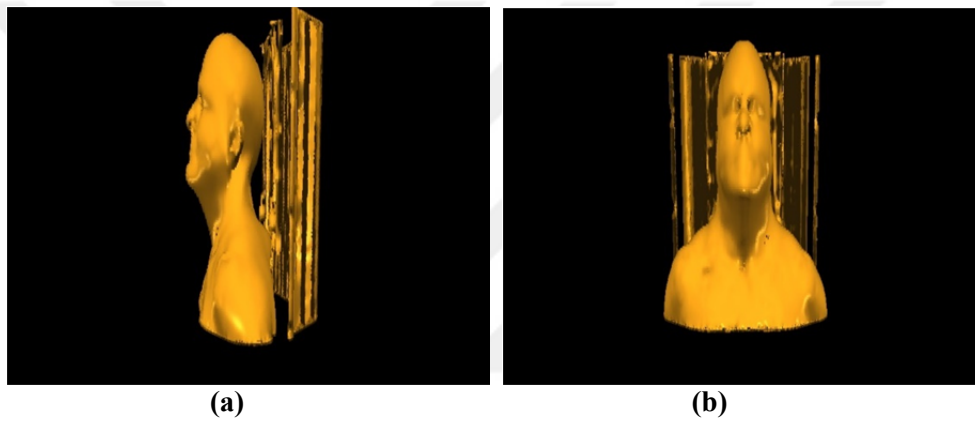


Figure 5.1. 3D Rendered image of a Headneck Cetuximab dataset. a. Sagittal, b. Frontal

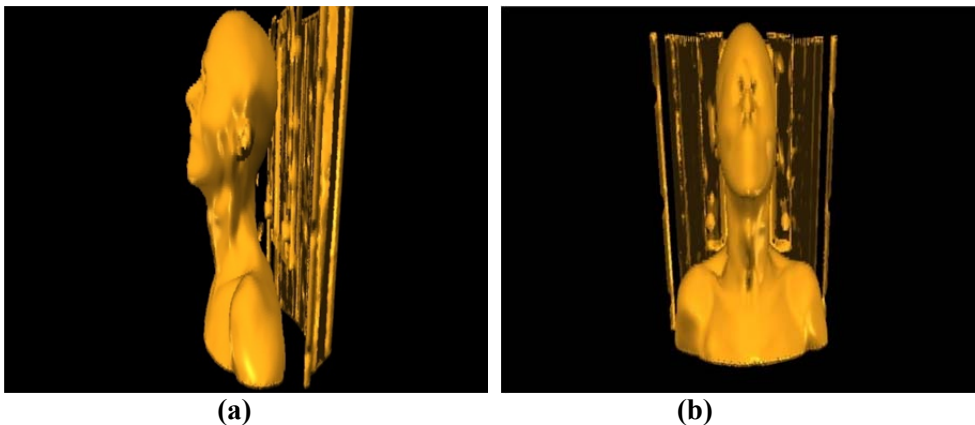


Figure 5.2. 3D Rendered image of a Headneck Cetuximab dataset. a. Sagittal, b. Frontal

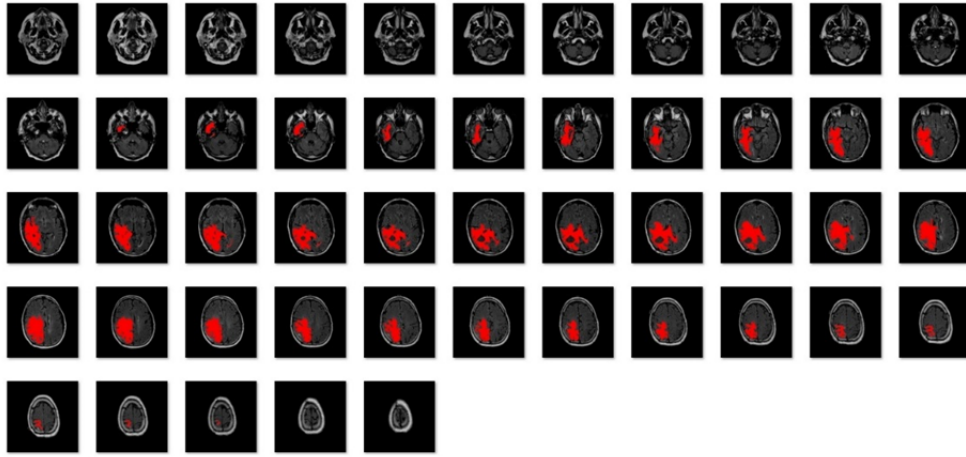


Figure 5.3. Dataset 1 detection.

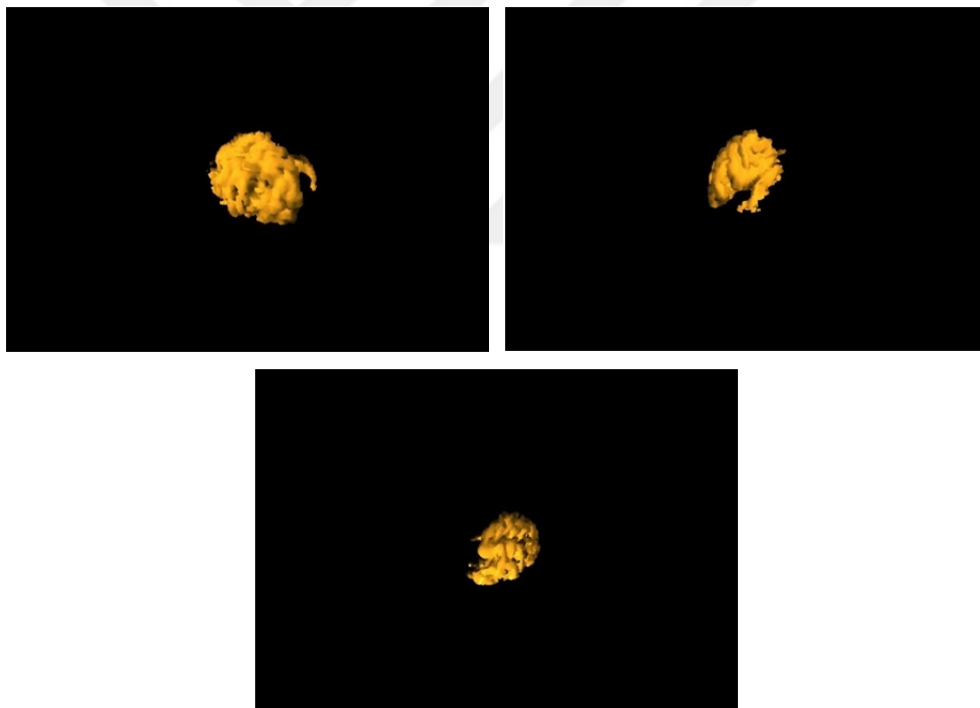


Figure 5.4. Tumor 1 from 3 different angles.

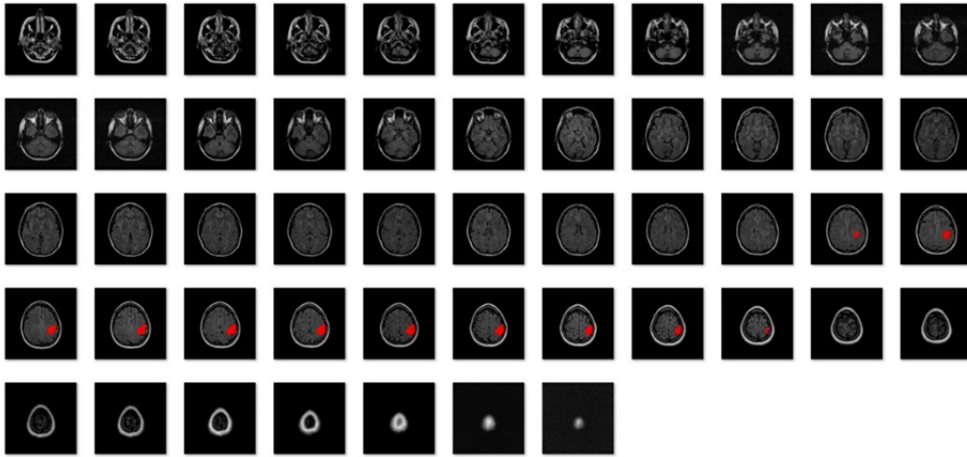


Figure 5.5. Dataset 2 detection.

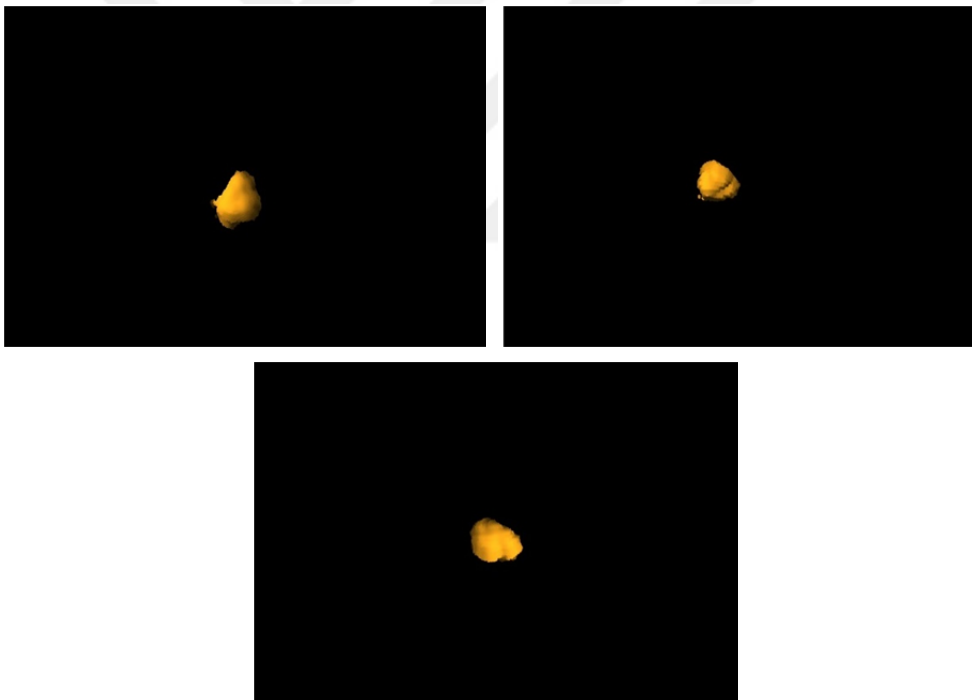


Figure 5.6. Tumor 2 from 3 different angles.

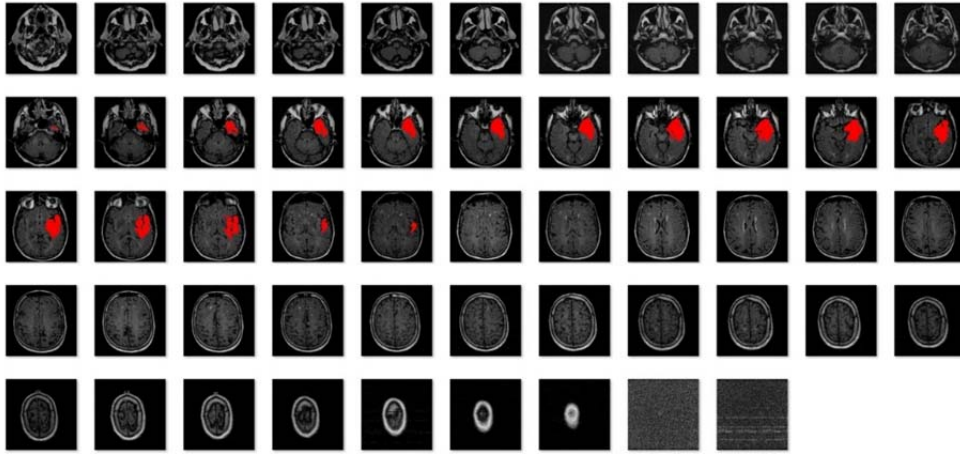


Figure 5.7. Dataset 3 detection.

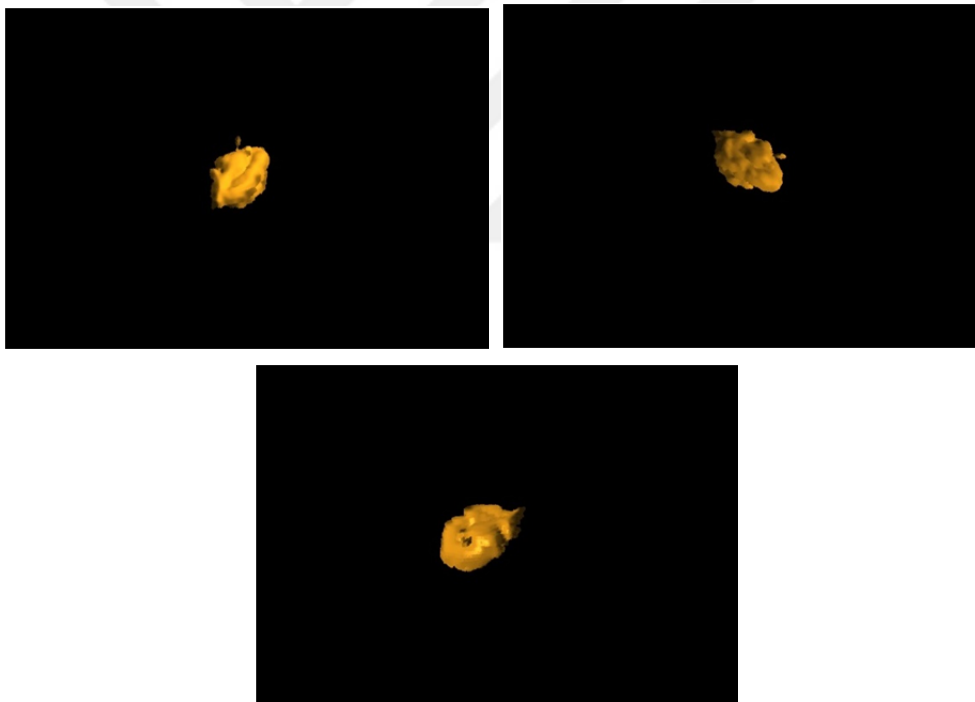


Figure 5.8. Tumor 3 from 3 different angles.

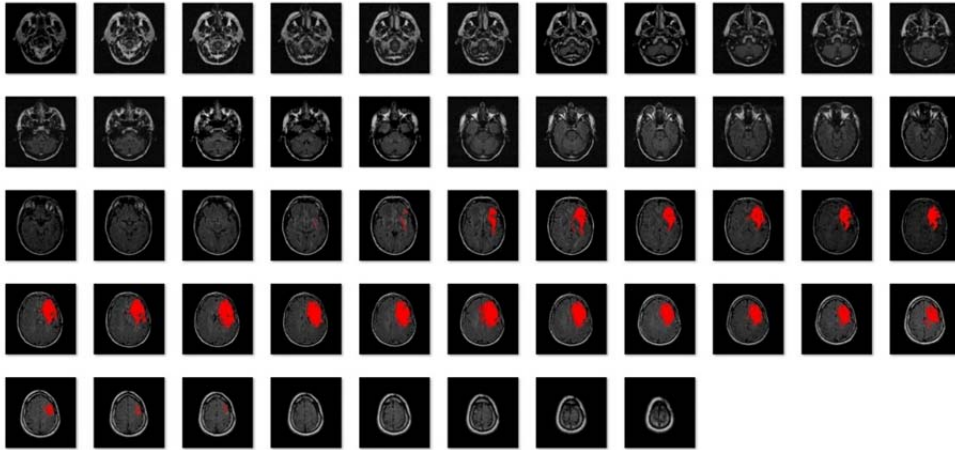


Figure 5.9. Dataset 4 detection.

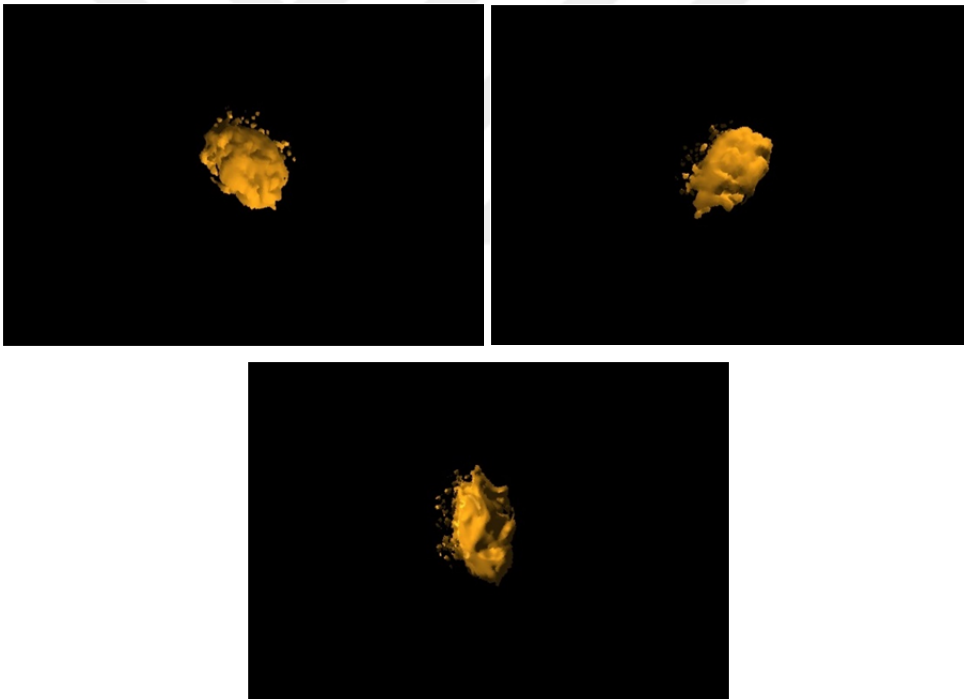


Figure 5.10. Tumor 4 from 3 different angles.

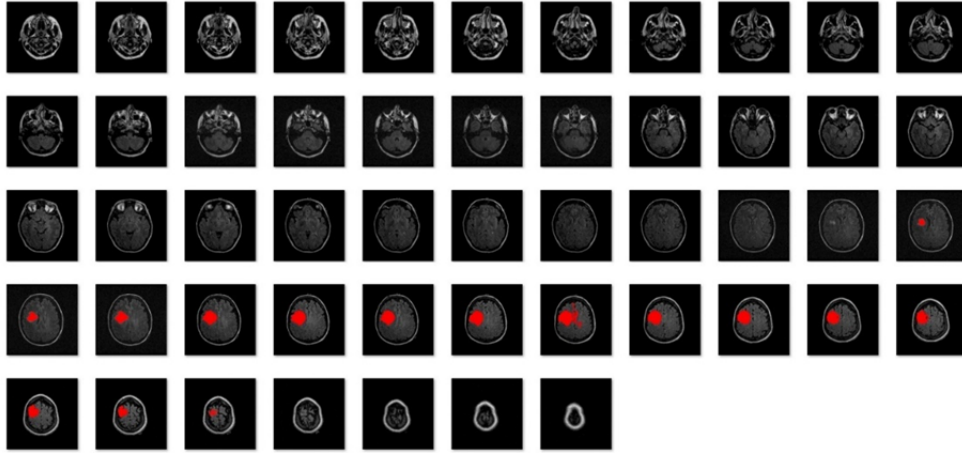


Figure 5.11. Dataset 5 detection.

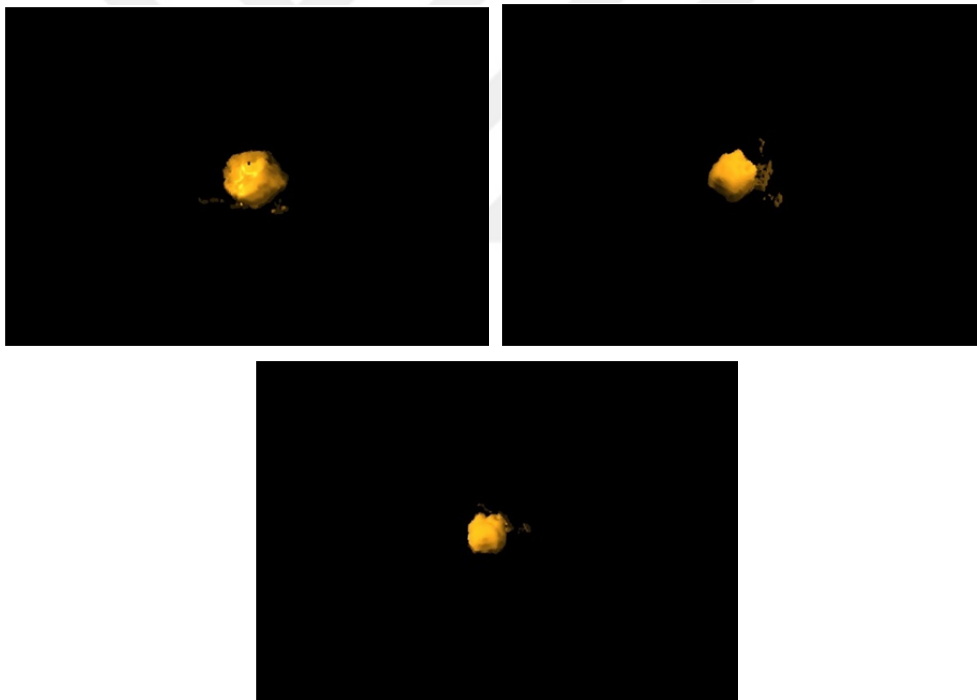


Figure 5.12. Tumor 5 3 different angles

6. DISCUSSION

A total of 256 slices from 5 different datasets was processed which consist of 49,51,53,52 and 51 slices respectively. 99 detections made in these datasets; 35,11,16,22 and 15 respectively. In 1 of the slices, the tumor was totally missed. In 3 slices there is detection but a small part of it is missed. In 7 slices, there are extra filled tumor parts which cause a little noisy 3D image. There was no wrong detection.

In medical imaging, the final processed image quality is very important since it must give accurate and realistic results to provide information and to help diagnosis. There are three image quality aspects; subjective, objective and perceptual measurement. Subjective measurement is the numerical satisfaction values of a number of viewers. In objective measurement, mathematical deviations between processed images and original images are calculated. Perceptual quality measurement is related to the human visual perception. Since human can extract information from viewing a field, it is considered to be an accurate quality metric (Çelebi and Çevik, 2010).

The output image quality is perceptually satisfying even for the low-resolution images of the tumors. The realistic output image obtained from the CT HEAD dataset proves that the volume rendering algorithm works efficiently and the output images of the tumors look realistic.



7. CONCLUSION

This study was carried out in 4 steps. The first step was the research and the study of the algorithms used in image segmentation and volume rendering, and obtaining the datasets to be used. After gathering the datasets and enough information about the algorithms, the second step was trying different combinations of image segmentation algorithms on the datasets to achieve accurate detection. A good combination was obtained which was given in Chapter 2. The next step was to apply volume rendering algorithms to obtain the 3D model. An option was added to the software to render both tumor detections and any type of 2D slice datasets, such as CT or MRI without any process. Volume rendering objective was completed by using the CT HEAD dataset because it is hard to understand the success rate with the tumor detections since they have unpredictable random shapes. In the last stage, the user interface was improved, and some tools were added to the software so the inspection can be done better.

Use of the developed software can save time and reduce human workload. More information can be obtained out of 2D slices in a short time and if there is an operation that needs to be done, visualization of what you are going to deal with can be shown. This means better preparation for the operation, which will greatly increase the success rate of it.



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CURRICULUM VITAE

Devrim KAYALI was born in Gazimağusa, North Cyprus in 1994. He received his Bachelor of Science (B.S) degree in Electrical-Electronics Engineering Department from Çukurova University in 2016. He started Master of Science (MSc) education in Electrical-Electronics Engineering Department of Çukurova University. His research areas are Image Processing, Computer Graphics, and Volume Rendering.

