Three Dimensional Image-Guided Surgery

SSY091 - Biomedical Instrumentation

Project Report Written by

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Contents

Abstract

This article provides an investigation to basic process of three dimensional image-guided surgery as well as clinical applications in realistic scenario. All information is gathered from relevant papers, websites and a visiting to a company as well. Knowledges about the technique of constructing three dimensional images and the methods to plan surgery procedures are introduced with necessary description and plots. A discussion about the development of this technology in the future is considered eventually.

Key words: image-guided surgery, image processing, 3D reconstruction, brain tumor surgery, vessel simulation.

1 Introduction

As the development of imaging techniques, medical images have been widely applied to diagnosis various diseases and plan surgeries. Medical imageing equipment, such as X-ray apparatus, computed tomography(CT), magnetic resonance imaging(MRI), ultrasound scanner etc., are able to provide images with high quality. A growing number of diseases can be detected by analyzing medical images. Recently, imaging technique is playing a more important role on surgery planning. In the beginning, 2 dimensional(2D) images are regarded as guidance to plan surgery. However, due to the faster imaging speed and better algorithm for image technique, 3 dimensional(3D) images are much accounted of planning surgery[1, 2, 3]. Comparing to 2D images, 3D images give more graphical internal structure of human body. A sample of brain tumor surgery guided by images is shown in Figure 1.1.

The following organization in this literature review is divided into four chapters. Chapter 1 introduces the methods to collect information of the topic. Main points of 3D image-guided surgery are detailed in Chapter 2, being followed by a discussion chapter about the limitation and future development of this technology. The conclusion of the report is presented in last chapter.

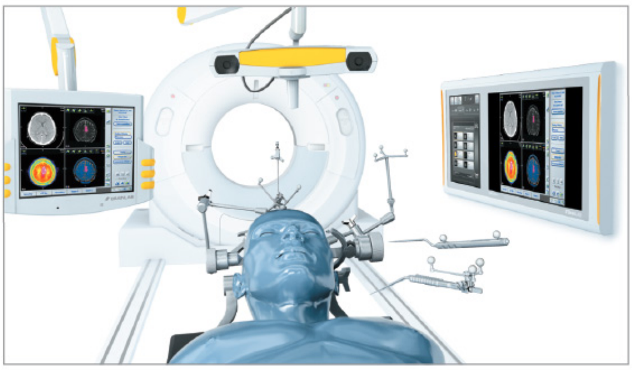


Figure 1.1: *Image-Guided Brain Tumor Surgery[4]*

2 Methods

The study method our group followed includes several steps. Firstly, we searched numerous information in general on the Internet in order to initially learn about our topic. Then, we organize the structure of report and choose the important field we would pay attention to. Each member of group has own task to study, so we need more materials including paper, book, video, website, etc. to support us to complete this report.

3 Results

The chapter of results is organized into four sections, which are the overview of 3D image-guided surgery system, the precess of 3d images construction, an introduction of image-guiding technique and clinicle applications in real situations.

3.1 Overview of System

In the 3D image-guided surgery system, 2D slices of specific part of body are obtained by CT or MRI scanners at first, after which some image processing technologies are applied to form 3D images and generate suggestions to surgeons to plan the surgery procedures. Lesion area of body is scanned by imaging equipment into a series of 2D images that contains critical information. These images are processed by algorithms to segment the regions of interest, such as organs, vessels or tumors. Technologies of image processing chiefly consists of enhancement, morphological operation and object segmentation to obtain valuable information, combining algorithms to reconstruct 3D images. Surgeons develop the surgical approach based on images to avoid injuring vital structures and offer a minimally invasive[5]. In the course of surgery, a navigation system is carried out to track surgical instruments to monitor their movement inside the body. Meanwhile, the internal structure of body is displayed in the screen through the method called volume rendering. Figure 3.1 shows the block diagram of 3D image-guided surgery system. In the next three sections, reconstruction of 3D images, image processing technologies as well as several clinical applications are introduced respectively in details.

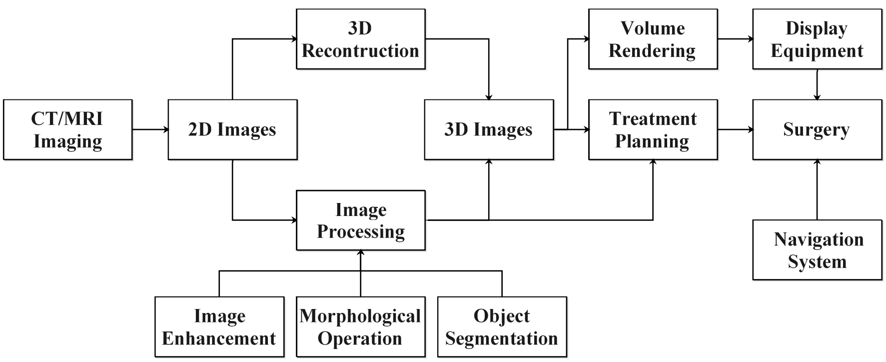


Figure 3.1: *Block Diagram of 3D Image-Guided Surgery System*

3.2 Construction of 3D Images

The reconstruction of 3D images is composed of gathering 2D slices of interested body area and combining all slices to stereo image according to the information of each slices position and details. There are several medical equipment that can form images of internal information from body, for instance, CT, MRI, ultrasound, optical imaging devices and so on. Comparing with other equipment, CT and MRI have many advantages including high spatial resolution, penetrability to all tissues and real-time imaging without contrast material[6]. What's more, CT and MRI scanner provides the cross-sectional images of human body, which is more handily and graphically reconstruct the body structure. After obtaining images, information of each slice will be extracted, including slice's position and segmentation of different interested area. Putting all slices into 3D system of coordinate and just showing region-of-interest of each slice to generate 3D structure. Eventually, 3D information is displayed in a 2D-formation by applying the algorithm of volume rendering. In this section, a brief introduction of CT and MRI will be given, and volume rendering is explained with a simple case.

3.2.1 CT/MRI Scanner

CT and MRI scanners are able to obtain cross-sectional images of structure of inner body. The theory of CT imaging is based on that different tissues have various abilities to absorb X-ray's energy, causing uneven distribution of X-ray on the detector. Then, all data received by detector under different angles are superposed together to reconstruct a 2D digital picture. The principle of MRI is that the part of body is added magnetic field with different intensity, resulting in the spin of atomic nucleus, hydrogen nucleus primarily, to move these atoms into different energy state. After which, the magnetic field is removed and atoms start to regain the initial state with energy releasing. Due to the various density of atomic nucleus, detector can receive different energy from parts of body. Thus, in fact, MRI imaging is a way to show the distribution of atomic nucleus of inner body. Compared to CT, MRI can provide a higher contrast between different tissues and safer situation for human[6].

3.2.2 3D Reconstruction

After obtaining 2D slices from CT or MRI scanner, 3D structure should be established to make information more graphically. A simple case made by using Matlab is shown as Figure 3.2, describing how to reconstruct MRI slices into a 3D model. It is can be seen that there are twenty seven MRI slices of skull contain details. Next step is putting all slices into 3D of coordinate to form a cube, in which the information of skull is remained under the surface. After which, every slice should be processed by some methods, such as image enhancement, morphological operation and object segmentation that will be explained in next section, to make the skull more remarkable and remove resting part. To show the 3D images on display equipment, volume rendering algorithm should be applied to transfer 3D information on the 2D screen. A typical method is called ray casting that shows the nearest object away from human eyes[7].

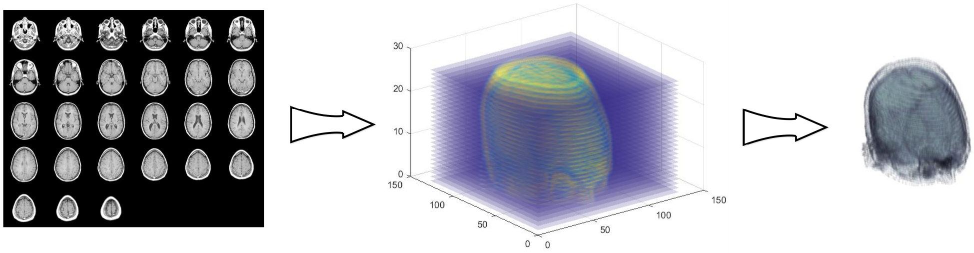


Figure 3.2: *Reconstruction of 3D Image*

3.3 Technology of Image Processing

Once an image has been captured it needs to be processed so that it can be further analysed by the system. Some techniques such as smoothening and sharpening of images are used for the purpose of image enhancement. These techniques are used for identification and differentiating organs in the body, also for determination of point of surgery.

3.3.1 Enhancement and Morphological Operation

Image enhancement is one of the first techniques that are used when an image has been captured. It helps enhance all the objects in image and helps in reducing the noise in the image. Figure 3.3 shows the original image on the left and the enhanced image on the right. As it can be seen the boundaries for all the objects become more clear and it is also seen that the noise/blur in the image has significantly reduced. The morphological operations such as erosion, dilation, opening and closing that are mainly used for image processing. These operations are usually binary in nature. They help in enhancing certain features in an image.

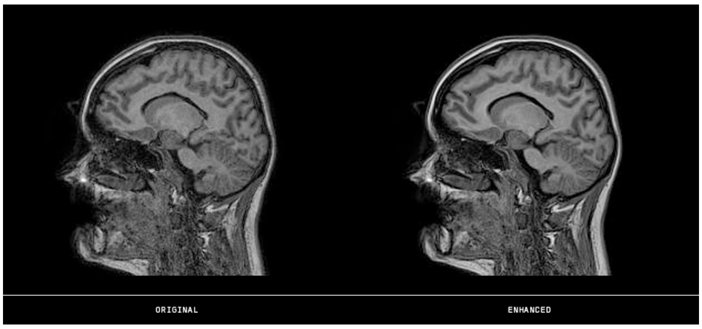
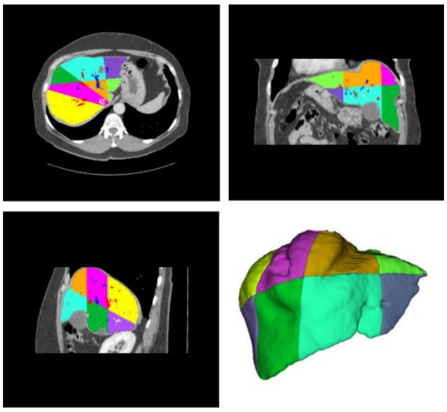


Figure 3.3: *Image Enhancement[8]*

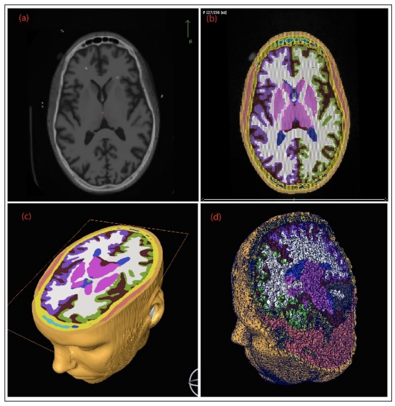
3.3.2 Image Segmentation

The process of image segmentation takes place to digitally assign a group of pixels together such that they become easier to analyse and understand. Image segmentation can be used for many other purposes such as object detection face detection finger print recognition among others. There are many techniques that can be used for the purpose of image segmentation. The most commonly used technique is that of thresholding. Thresholding is technique of image segmentation in which a threshold value is set such that the colour image is converted into a grayscale/binary image, which makes it easier for the system to identify and differentiate boundary or objects in the image. There are other methods such as clustering based, compressing based methods, edge detection and many more that are also used for the purpose of image segmentation.

The process of object identification and classification is very important when it comes to 3D Image guided surgery since misclassification of pixels would lead to irregularity in the way the object is seen thus increasing the risks of a surgery. The following Figure 3.4a shows the image segmentation of a liver. The Figure 3.4b shows how an MRI image has been segmented using various techniques such as clustering and thresholding.



(a) *Segmentation of Liver[9]*



(b) *Segmentation in MRI Images[10]*

Figure 3.4: *Image Segmentation*

3.4 Application of Imaging Guided Surgery

Imaging guided surgery(IGS) is an advanced and comprehensive method to help surgeon to plan surgery, thereby increasing accuracy and efficient of surgery. This technique can be applied to many fields of surgeries, such as tumor resection, endovascular simulation, cosmetic surgery, etc. In this report, we will focus on two applications which pay attention to the brain tumor and endovascular simulation.

3.4.1 IGS for Brain Tumor

IGS is becoming an essential tool for brain tumor surgery, because the skull cannot show anything about the location of tumor, leading to surgeon have to cut big opening window bone conventionally in order to find the tumor. In IGS, information from MRI or CT can be uploaded to a system, which is very similar to GPS system used for car.

As GPS could help people find spot and how to get there, IGS can navigate to the tumor.

There are many components in the real tumor navigation system as shown in Figure 3.5. They are pointer, reference frame, camera and computer. Camera can emit infrared light and there are some small reflective balls on the reference frame. Pointer with reflective ball as well can be used to point the skull, and these references will be back to the camera and uploaded to the computer[11].

Normally, surgeon will follow several steps to make a good brain tumor resection surgery. First of all, patient is supposed to be scanned by MRI in order to image acquisition, and then this image data will be processed by computer system. It is a very specific and smart software which could transform preoperative image data into semi-automatic and intraoperative images displayed on the computer screen. Usually, surgeon put some spots on patients face, and these spots are called fiducial markers which can be seen on MRI. Patients head should be immobilized in the reference frame, this reference and fiducial markers are used to registration during surgery[12].

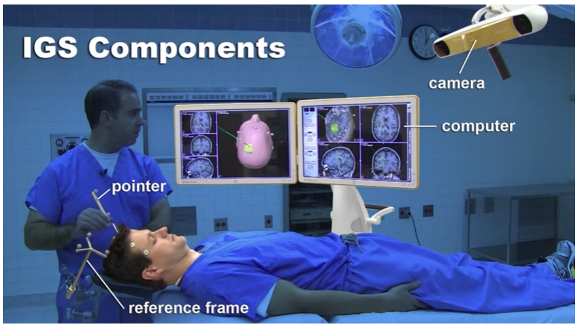


Figure 3.5: *IGS Components in Real Brain Tumor Resection Surgery Operating Room[11]*

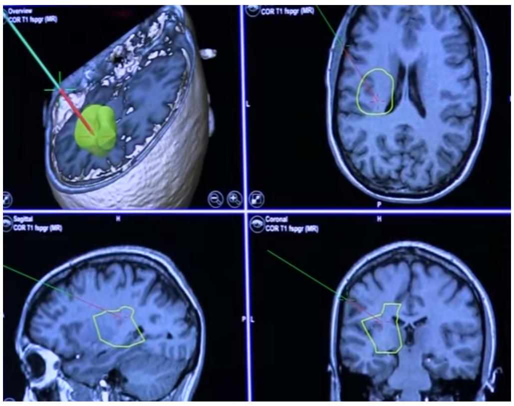


Figure 3.6: *Using Pointer to Localize the Tumor[11]*

Second step is registration, this is the step we are going to bring the patient to match the 3d data from MRI. First of this step is to register the fiducial markers on the MRI, surgeon could point the markers with pointer, and camera can sense the pointer and reference frame then match these data on the 3D map. Next step is navigator to the tumor, now the patient has been already registered. As shown in Figure 3.6, surgeon uses the pointer to localize the tumor, and the real time triplanar images are displayed on screen. Surgeon is able to use the pointer to localize the tumor, then map the location on the skull, this can make opening window of bone as small as possible.

Next, surgeon could perform craniotomy to work into the brain to find the tumor and remove the tumor. Final step is to confirm tumor removal, using the pointer to examine the edge of tumor inside brain, the camera senses the pointer and places location on the computer screen. Surgeon moves pointer around to accurately identify the edge of tumor in order to confirm that all tumor is removed before finishing the surgery. It is obviously that surgeon takes advantage of IGS to make a plan prior to surgery can improve the efficient, accuracy and safety significantly.

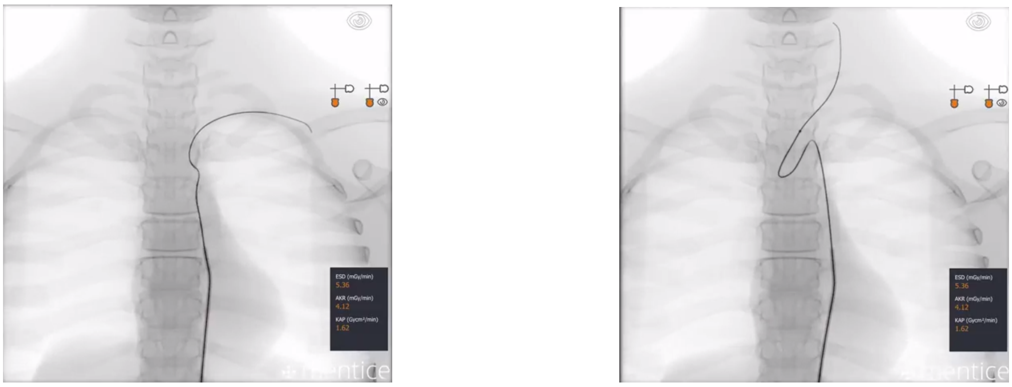
3.4.2 Endovascular Simulation

Mentice is an advanced company which focus on the endovascular detection and simulation. This biomedical instrument company develop a series of smart simulation system and devices including simulated operating table, computer screen and catheter, to help surgeon to make practice preoperatively in order to improve surgeons confidence and accuracy. Several endovascular diseases could be supported by this simulation system, like stroke, valve implantation, cardiac rhythm management, etc[13]. In this report, we are going to take Acute Ischemic Stroke Intervention as example to illustrate how this system works.

Stroke is a kind of disease caused by atherosclerosis results in never cells in persons brain are damaged to some extent. This damage usually could cause the capacity of speech or movement lose, because there are thrombus in the brains blood vessels to stop oxygen from transmitting into targeted nerve cells. It is impossible for surgeon to make minimal invasive surgery from head directly, because the clot area is deeply inside brain and hard to localized. Conventionally, doctor uses some ways to dissolve the clot to treat stroke, this method is not only inefficient which means low recover rate, but also bring side effects to patient.

Mentice could use its system to make clot retrieval practice for surgeon. Firstly, patient will be scanned by CT or MRI in order to image acquisition, then this image will be transferred to the computer and displayed based on different requirement in real time. Then, surgical instruments are catheter and wire with different diameters.

Then, surgeon uses catheter cooperated with thinner wire to practice detecting the visual endovascular environment of body. The start point is located in abdominal region due to consideration of safety and convenience. Catheter is putted into the blood vessel as shown in Figure 3.7. Surgeon have to follow right path of vessel, it is not easy for a newcomer. When catheter faces different turning, surgeon could inject a poisonless substance to make contrast of image to distinguish different vessels. The process catheter passes through cardiac region is called cardiac access, bent and reverse shaped catheter as shown in (b) of Figure 3.7 means it has already enter aorta through heart.



(a) *Entering cardiac region* **(b)** *Entering aorta*

Figure 3.7: *Cardiac Access of Catheteration[14].*

When catheter is into the brain, the task is to localize the vessel which has clot. As shown in Figure 3.8, a white vessel in Figure **??** does not have any path forwards, this means that this vessel is clotted because poinsonless substance injected cannot pass through it. Now, surgeon can use thrombectomy and aspiration devices to remove thrombus. When thrombus is removed completely, the image will be shown will be shown as b in Figure 3.8. All these steps are made on simulating operating table, and all endovascular environment and surgical process are visual. This system absolutely could provide enough time for surgeon to make practice, thereby increasing accuracy and lowing risk of patient.

(a) *Aspiration of thrombus* **(b)** *Thrombus is removed*

Figure 3.8: *Acute Ischemic Stroke Intervention[15].*

4 Discussion

Although IGS is a very helpful tool to support surgeon to make surgical plan, there are also some disadvantages inside it. In order to implement IGS system, image acquisition is needed and patients have to be scanned by CT or MRI preoperatively. The image data acquired is "yesterday"[16] rather than latest when image is used to implement surgery. With regard to patients, they are exposed to extra dose of radiation to some extent and it is also harmful for patients who are claustrophobic to spend much time in MRI machines long tube. Additionally, patients own error should also be considered when computer processes the image data[17].

The advantage of using IGS system is obvious, it could help surgeon to not only learn about patients precise anatomy preoperatively, but also localize the place where disease (tumor, clot, etc.) occurs in real time on the screen. This system is also very helpful when surgeon has removed tumor or cleaned clot because IGS system could also help surgeon to identify whether this area is finished completely or not and know if the tissues around this area are damaged in order to keep safe[17].

5 Conclusion

Image guided surgery has been considered as an advanced method applied to some fields like tumor surgery and endovascular surgery. Surgeon can make surgical plan efficiently and accurately in order to keep patients safety via this advanced system. This is a kind of assistant way to support surgery rather than change or create procedures during the surgery[17].

In the future, this method could be applied to more and more fields even if it has some insignificant disadvantages. And a new technology called augmented reality (AR) is also applied to image guided surgery in order to help surgeons focus on the real-time image in front of them instead of glancing at screen several times.

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