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Simulation of the Virtual Reality based Robotic Catheter System

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Abstract - **Minimally Invasive Surgery (MIS) is a specialized surgical technique that permits vascular interventions through very small incisions and minimizes the patient's trauma and permits a faster recovery compared to traditional surgery. Telemedicine is one area where remotely controlled robots can have a major impact by providing urgent care at remote sites. However, the significant disadvantage of this surgery technique is complexity and it requires extensive training before surgery. The unavailability of force and tactile feedback the operator must determine the required action by visually examining the remote site and therefore limiting the tasks. In this paper, we present virtual reality simulators for training with force feedback in minimally invasive surgery which allows generating realistic physical-based model of catheter and blood vessels, and enables surgeons to touch, feel and manipulate virtual catheter inside vascular model through the same surgical operation mode used in actual MIS. In this paper, the design of the MIS VR system and initial experimental results are presented and the experimental results show that the error rate is in an acceptable range and the simulators can be used for surgery training.**

Index Terms **–Virtual Reality based Robotic Catheter System, Catheter, Minimally Invasive Surgery (MIS).**

I. Introduction

As the simple operation, with small pain and less risk of postoperative recovery for the surgeon, Minimally Invasive Surgery (MIS) is widely accept and applied in many medical fields. Minimally invasive surgery is a kind of revolutionary surgical technique, surgeries are operated using precise medical devices and viewing equipments inserted through a small incision instead of making a large incision to expose the operation site. The main advantage of this technique is to reduce the health tissue, such as patients' pain and scaring and prolonged hospital stay. However, there are some critical disadvantage of this surgery technique, they are so complicated, the technique requiring extensive training efforts of the surgeon to achieve the competency, because the arteries through which the catheter passes are extremely intricate and delicate.

Minimally invasive techniques have unavoidable reduced the sense of touch compared to open surgery, surgeons have to rely more on the haptic feeling generated by the interaction between blood vessels and the catheter. Even if the colour and texture of blood vessels convey crucial anatomical information visually, touch is still critical in the surgeries. The benefits of using haptic feedback devices in minimally invasive surgery training through simulation have already been recognized by several research groups and many of companies working in this area. However, in these researches, the virtual surgical training were carried out without haptic feedback, or researched on the virtual model of body organ not the vascular physical model. Moreover, some achievements in this area used Phantom Omni or other haptic devices as a controller to operate the virtual minimally invasive surgery. Nevertheless, it is not convenient when surgeon drive the catheter for inserting and rotating because it does not accord with the custom of surgeons' operations.

Also there are some product have been developed in a few years. One of the most popular product is a robotic catheter placement system called Sensei Robotic Catheter System offered by Hansen Medical. The Sensei provides the physician with more stability and more force in catheter placement with the Artisan sheath compared to manual techniques, allowing for more precise manipulation with less radiation exposure to the doctor, commensurate with higher procedural complications to the patient. Because of the sheath's multiple degrees of freedom, force detection at the distal tip is very hard. Catheter Robotics Inc. has developed a remote catheter system called Amigo. This system has a robotic sheath to steer catheters which is controlled at a nearby work station, in a manner similar to the Sensei system. The first in human use of this system was in April 2010 in Leicester UK, where it was used to ablate artificial flutter. Magnatecs Inc. has produce their 'Catheter Guidance Control and Imaging' (CGCI) system. This has 4 large magnets placed around the table, with customized catheters containing magnets in the tip. The catheter is again moved by the magnetic fields and is controlled at a nearby work station. The system facilitates precise vector based navigation of magnetically-enabled guide wires for percutaneous coronary intervention (PCI) by using two permanent magnets located on opposite sides of the table to produce a controllable magnetic field.

In this paper, we prepare to develop a Virtual Reality based on Robotic Catheter System for surgeons' training in minimally invasive surgery. The system can generate the realistic virtual reality environment of blood vessels and allow to simulate surgeon's operating skills to insert and rotate catheter like surgeon operates catheter directly and carry out the intervention with haptic interfaces with force feedback, which provides the surgeon with a sense of touch.

This paper is organized as follows. Section 2 introduces the structure of the Virtual Reality based Robotic Catheter system. Section 3 presents the algorithms and implementations of cerebrovascular model, catheter model and the interaction between cerebrovascular vessels and catheter. Section 4 discusses the results of our virtual reality simulators. Section 5 describes our further directions, and concludes the paper.

II. STRUCTURE OF THE VIRTUAL REALITY BASED ROBOTIC CATHETER SYSTEM

The Virtual Reality based Robotic Catheter System could be used in operation training and remote catheter control, as shown in Fig. 1. We have designed the master-slave catheter operation system as shown in Fig. 2 and Fig. 3. In the master side, surgeon operates the handle to drive the catheter for inserting and rotating to clamp catheter directly, the control commands of the catheter operating system were transmitted to the slave side, after the slave side PC receiving the control commands from master side, the mechanism clamps the catheter to insert and rotate inside the blood vessel and at the same time simulate the surgeon's operating skill. The load cell was used for detecting the frictional force between catheter and blood vessel, the torque sensor and motor were used for detecting rotating information of catheter, and could be transmitted to the surgeon's hand in master side. Then surgeon can decide whether inserting or rotating the catheter depending on the feedback information and the visual information.

On the slave side, the catheter manipulator is as well as the controller; it means that the catheter manipulator could keep the same motion with the operator's hand. During the operation of intravascular neurosurgery, it is significant to obtain the contact force information between catheter and blood vessel. In order to detect the contact force information between catheter and blood vessel, we developed an intelligent force sensors system for robotic catheter systems. By using the developed force sensors system, we can obtain the contact force information and feedback it to the surgeon. So that, surgeons can decide whether insert or rotate the catheter depending on the feedback information and do not have to use X-ray during intravascular neurosurgery. If there are no force sensors on the catheter, it is easy to damage the blood vessel during operating, because the blood vessel is fragile.

For this system, we can transmit the DICOM3.0 image to the master side, the camera image show us the extern information and the DICOM image show us the inner information of the sick. The Surgeon in the master remote side can carry out the operation according to the two kinds of 3D image and complete the next operation step. However, the DICOM 3D image should be converting by us, and it is our important work to overcome so many unpredictable factors and difficulties.

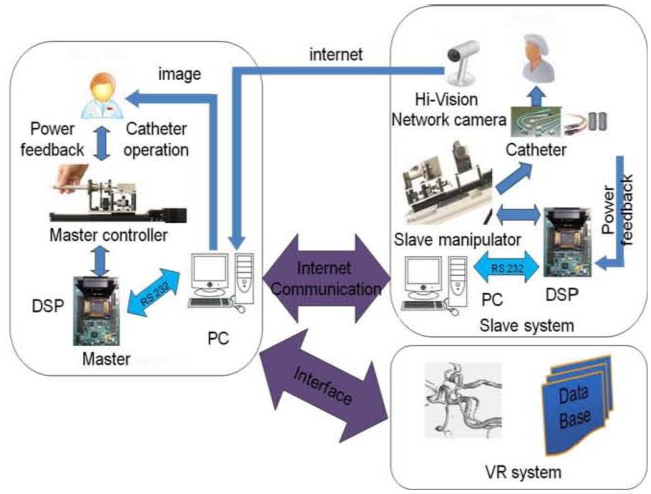


Fig. 1 The structure of the virtual reality based robotic catheter system

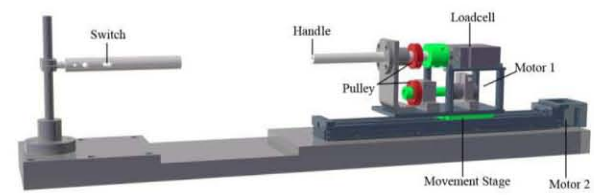


Fig. 2 the Robotic Catheter Master System

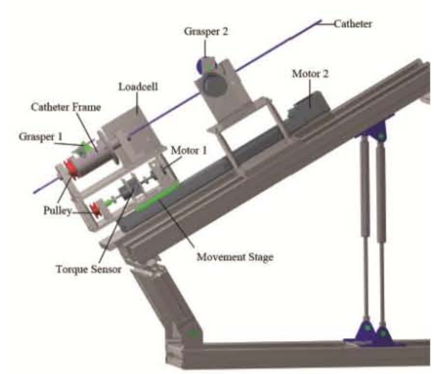


Fig. 3 the Robotic Catheter Slave System

III. RECONSTRUCTION OF THE MODELING OF 3D VESSEL

To develop realistic physical-based vascular models which are the virtual representations of real blood vessels that display accurate displacement and force response, the shape and the material properties of blood vessels should be measured and characterized in living condition and in their native locations. Models with incorrect material properties and shape could result in adverse training effects. In order to reconstruct the realistic three dimension vascular model, we apply median filter algorithm to reduce the noise of the CT images, then use local thresholding algorithm to realize the image segmentation of CT images, finally adopt the volume rendering technology to reconstruct the vascular model. We should use the software Cmake to install the DCMTK to the VC++ package. We need install "DCMTK 3.5.4-source code packages", "DCMTK 3.5.4-support libraries for windows", "Cmake 2.8.4 (one of Packages compiled tools)" . Then we can use DCMTK to complete the image segmentation, as shown in Fig. 4. CFile Dialog can be used to open the DICOM files, and Dicomimage class is important to deal with the DCM file and output the information what we want, dcmdapfn can be used to export standard display cures to a text file, dcod2lum can be used to convert hardcopy characteristic curve file to softcopy format. Then we can create DIB and initialize the image information. Set window() is used to adjust the windows. Image grey value calculation formula can be shown in equation (1). According to the CT value of the DCM file which can present different parts of the human body, it is possible for us to change the grey value in the program and realize image segmentation.

$$G(V)=\begin{cases} 0, & V<C-\frac{W}{2} \\ \frac{g_m}{W}\left(V+\frac{W}{2}-C\right), & C-\frac{W}{2}\le V\le C+\frac{W}{2} \\ g_m & V>C+\frac{W}{2} \end{cases} \qquad (1)$$

where, V means image data, G(v) means Value displayed, gm is the maximum value displayed, w is the display window wide, c is the window level.

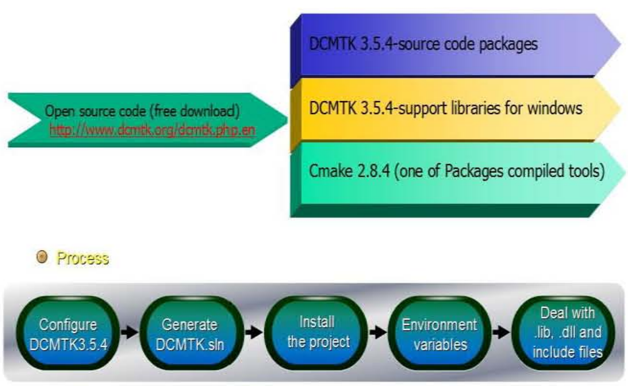


Fig. 4 Process of DICOM Image Segmentation

Fig.5 show the mesh method of the 3D vessel model. Volume rendering methods generate images of a 3D volumetric data set without explicitly extracting geometric surfaces from the data. These techniques use an optical model to map data values to optical properties, such as color and opacity. During rendering, optical properties are accumulated along each viewing ray to form an image of the data. We use texture mapping to apply images, or textures, to geometric objects. Volume aligned texturing produces images of reasonable quality, though there is often a noticeable transition when the volume is rotated.

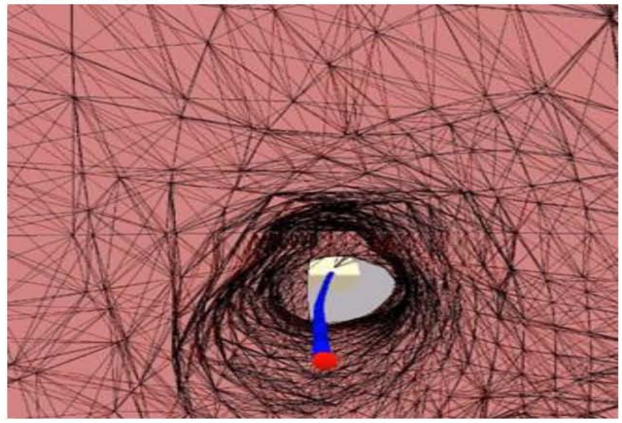
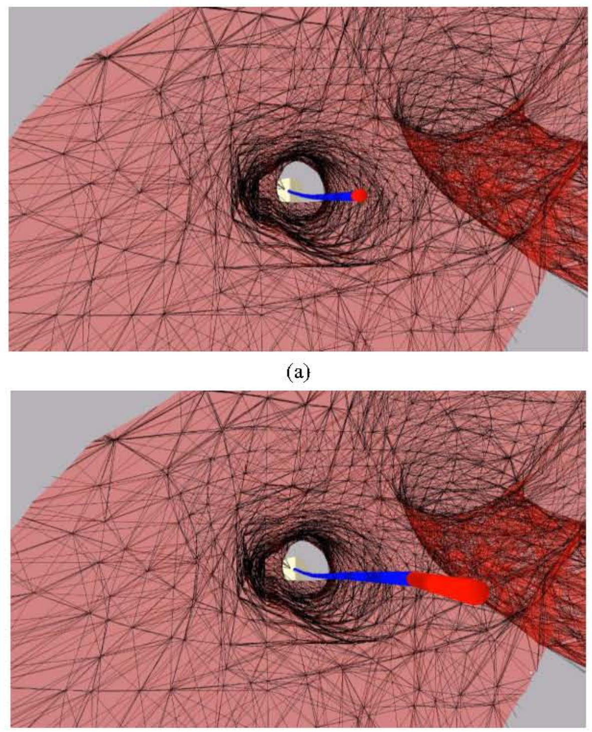


Fig. 5 the mesh method of the 3D vessel model



(a)

(b)

Fig. 6 The process of catheter inserting into the 3D vessel and collision of the vessel model and catheter model.

IV. Experiments and Results

As shown in Fig.6, we use the process of catheter inserting into the Physics-based modeling of 3D Vessel. In order to testify our physical model of blood vessel and catheter, we designed a series of collision experiments between the catheter and vessel to compare the simulation results of the physics-based modeling of the catheter with the real output of the force measured by contact force sensor in the slave side.

The red part of the catheter is the tip top part which is used to collect the force information of catheter when it contects with the vessel.

Fig.7 shows us the process of the collision of the catheter with the blood vessel model, and when collision happened, we can detect the tip force in the VR system and sent it to the user by the master side. So that, the doctor can get the force information and decide whether insert or rotate the catheter depending on the feedback information

In the VR system, we get the results which show that force trendline of the catheter-vessels interactions in virtual reality environment. There are many other complex interactions between the catheter and the vascular vessels and the process of deformation turns to be a little rigid, and it may generate calculation error of elastic force.

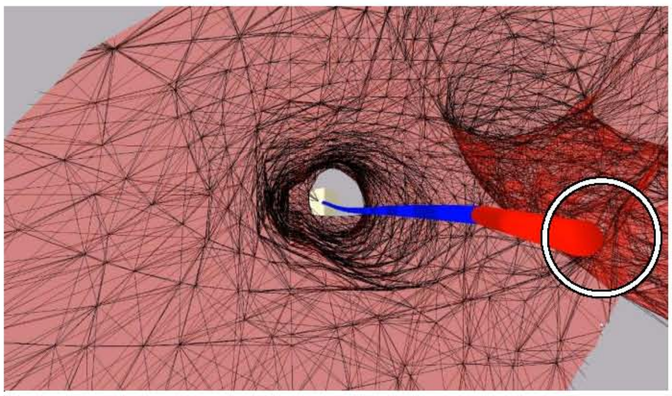


Fig. 7 Deformation of the catheter and 3D blood vessel model in the collision.

V. CONCLUSIONS

The Virtual Reality based Robotic Catheter System is used for the training of the interns to operate the Robotic Catheter System and improve the operation experience and auxiliary medical process. The system is designed to simulate the motion of catheter during the operation procedure. The motion of catheter could be divided into two kinds, movement along the axial direction of the catheter and rotation about the radial direction of the catheter. The system has good manoeuvrability, it can simulate surgeon's operating skill to insert and rotate catheter.

The result of the work presented here is the virtual reality simulators allowing for the simulation of surgeon's operations for training in minimally invasive surgery based on our novel robotic catheter operating system. Based on the virtual model of catheter and blood vessels, we analyze and apply physical-based theory and implementation for these models. And the experimental results show that by defining the material properties of the catheter and the blood vessels, the behaviour of the catheter motion can be realistically simulated in a specific patient artery network, thereby allowing surgeons to train and rehearse new operative skills repeatedly. In the future works, we will use the Virtual Reality System to help the unskilled surgeon improve their experience and safety of the operation.

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