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A Method of Decreasing Time Delay for A Tele-surgery System

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***Abstract* - The haptics-based master-slave system for Minimally Invasive Surgery is a promising way to protect surgeons from long time radiation and to train novice doctors to learn basic wire or catheter handling skills. However, the time delay of transmission of visual video and the time difference between image information and force signals restrict the application of this technology in some extent. In this paper, we proposed a new method to reduce time delay effectively. At the slave side, the tip of the active catheter is tracked in real time to provide information on the location of the catheter in the blood vessel model. And then transmitted the coordinate values to the master site. At the master site, the location of the catheter was reappeared in the navigation chart which is the same structure with the blood vessels at master side according to the coordinate values received from the slave side. Therefore the transmission time of image information is decreased. Experimental results are given to illustrate the accuracy of our method.**

Index Terms* - *master-slave system, image processing, real time, time delay

I. INTRODUCTION

Minimally invasive surgery is a revolutionary surgical technique, in which surgeries are performed using precise medical devices and advanced equipments inserted through a small incision rather than making a large incision to expose the operation site. The main advantage of this technique is to reduce trauma to healthy tissue since this trauma is the leading cause for patients' pain and scaring and prolonged hospital stay. However, there are several problems associated with the conventional way of performing this technology because it requires extensive training efforts of the surgeon to achieve the competency, and the arteries through which the catheter passes are extremely intricate and delicate. Furthermore, the clinician has no feedback on the force applied by the tip of the catheter on the walls of the blood vessel. Excessive force could rupture the blood vessel or dislodge plaque. In addition, the surgeons could have prolonged exposure to radiation and be subjected to a high level of fatigue caused by poor ergonomics of the current procedure. These pose danger or discomfort to the surgeons who perform the procedure over a prolonged period of time [1]. There is, therefore, a need to develop technology for a more accurate, safer, and more reliable approach for catheter insertion that can reduce the potential for injury to patients and radiation exposure and discomfort to surgical doctors.

The haptics-based master-slave system for Minimally Invasive Surgery is a promising way to protect doctors from longtime radiation and to train novice doctors to learn basic wire or catheter handling skills. There are a few research groups that have studied the robotic tele-operative surgical systems with force feedback [2]-[7]. In general, a teleoperative surgical system comprises a master system at the operation site and a slave system at the surgery site (**Fig. 1**). The surgeon operates the master system at the operation site, and the actual operation is performed at the surgery site. The two sites can be connected by various networks such as LAN, ATM, and ISDN, and the robot control signal, images, voice, and other information are transmitted.

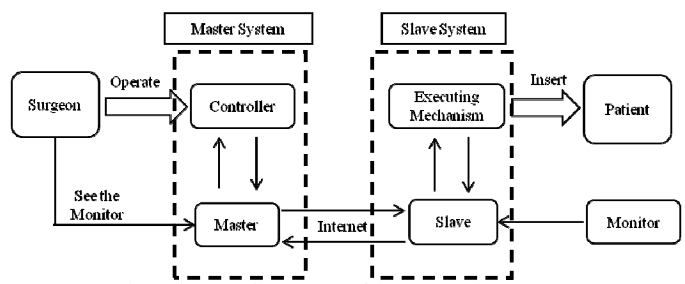


Fig.1 The overall structure of the master-slave system

But there are some unavoidable problems in using tele-operative surgical systems, the time delay of image transmission and time difference between force signals and image information. Force signals measured at the surgery site can be transmitted to the operation site much faster than image signals because the force information does not need to be compressed for transmission. Another important reason is the fact that the size of visual information is large and is much more than force signals. The incremental time delay and time difference are always associated with the significant deterioration of the operability and may result in damage to organs in actual surgery. Aiming at solving these problems, Sriram Natarajan et al introduced an adaptive packet prediction and buffer time adjustment algorithm which reduces the negative effects caused by the time varying networks on the transmission of force feedback data, and Yanjiang Yang et al proposed a pre-processing algorithm to reduce the time delay [8]-[9]. In addition, H. Hawkeye King et al tried to propose a new preliminary transmission protocol for the interoperable telesurgery and presented a preliminary specification for interoperability among robotic telesurgery systems and Kazushi Onda et al presented a synchronization algorithm to adjust the time gap between force signals and visual information, besides a method to predict force information was also presented [10] - [11].

In this paper, we proposed a new method to reduce the time delay of image transmission and the time difference between force signals and image information. In our approach, the tip of the catheter was tracked in real time to provide the coordinate values on the path of the catheter at the slave site and then transmitted the coordinate values to the master site. At the master site, the position of the tip of the catheter was reappeared in the navigation chart which is the same structure with the blood vessels at master side according to the coordinate values received from the slave side. The coordinate values from slave side can correct the position of the tip of catheter.

This paper is organized as follows. In Section II, the overall structure of novel robotic catheter operating system is presented in a systematical way. Section III cites the methods of reducing the time delay of image information. An experiment to verify our methods is described in section IV. Finally, a brief conclusion and future work section is presented in Section V.

II. The Novel Robotic Catheter Operating System

The conceptual principle of our novel robotic catheter operating system with a master-slave system has been shown in **Fig. 2-5** [12]-[17]. The surgeons manipulate the right handle to move forward and backward, or to rotate the right handle during operation in master side. The controlling information of master side can be transmitted to the slave side, and in the slave side the catheter clamping structure drive the catheter to insert or rotate according to the commands generated from the master side. If the catheter contacts the blood vessel wall, the contacting information can be detected by load cell and torque sensor, at the same time, surgeons can detect the force feedback in the master side. Therefore, the force feedback is realized by this new master-slave robotic catheter operating system, the surgeon can feel the contacting information with this catheter operating system.

The catheter system is designed with the structure of master and slave. The surgeon console of the system is in the master side and the catheter manipulator is in the slave side. Moving mode of the catheter manipulator is designed as well as the surgeon console. The movable parts of surgeon console and catheter manipulator keep the same displacement, speed and rotational angles, therefore, the surgeon could operate the system smoothly and easily. Each of surgeon console and catheter manipulator side employs a DSP (TI, TMS320F28335) as their control unit. An internet based communication is built between the surgeon console and the catheter manipulator. The console side sends axial displacement and rotational angle of the handle to the catheter manipulator. At the same time the catheter manipulator sends force information back to the console side. Serial communication is adopted between PC (HP Z400, Intel Xeon CUP 2.67GHz speed with 3GB RAM) and control unit of the mechanism. The baud rate of the serial is set to 19200.

A. The Slave Side of the Catheter Operating System

Fig.2 shows the catheter manipulator. This part is placed in the patient side. The catheter is inserted by using this mechanism. This part contains two DOFs, one is axial movement alone the frame, and the other one is rotational movement. Two graspers are placed at this part. The surgeon can drive the catheter to move along both axial and rotational motion when the catheter is clamped by grasper 1. The catheter keeps its position and the catheter driven part can move freely when the catheter is clamped by grasper 2. Inserting motion of the catheter is as shown in **Fig.3**.

To realize axial movement, all catheter driven parts are placed and fixed on a movement stage (the green plate under motor 1 in **Fig.2**). The movement stage is driven by a screw which is driven by a stepping motor (motor 2 in **Fig.2**). On the other hand, a dc motor (motor 1 in **Fig.2**) is employed to realize the rotational movement of the catheter. The dc motor is coupled to the catheter frame by two pulleys which are coupled by a belt with teeth. The catheter is driven to rotating by motor 1 when the catheter is fixed on the frame by grasper1.

Torque sensor is applied in this system to measure the torque information during the operation. The torque information will be sent to the controller side and generate a torque feedback to the surgeon. The torque sensor is linked to motor 1 and the axle of the pulley below. The resisting torque of the catheter can be transmitted to the torque sensor by coupled pulleys then measured by the torque sensor.

Resisting force acting on the catheter can be measured and will be sent to the controller and generated a haptic feedback to the surgeon. To measure the resisting force, a mechanism is designed as shown in **Fig.4** in detail. A loadcell which is fixed on the movement stage is employed to measure the resisting force. A clamp plate fixed on the loadcell is linked to the catheter frame which is supported by two bearings. The resisting force acting on the catheter in the axial direction can be detected by the loadcell when the catheter is fixed on the **Fig.4**: Force measurement mechanism frame. The clamp plate doesn't affect the rotating motion of the catheter frame.

B. The Surgeon console

Fig.5 shows the surgeon console of the RCMS. The surgeon console is the master side of the whole system and it is operated by the experienced surgeons. Surgeons carry out operations by using the console. A switch placed on the left handle is used to control these two graspers in catheter manipulator side; only one switch is enough because the catheter is clamped by one grasper at the same time. Surgeon's action is detected by using the right handle. The movement part of catheter manipulator keeps the same motion with the right handle of the console. The right handle can measure two actions of the surgeon's hand, one is axial movement and the other one is rotational movement. The handle is sustained by a bearing, and is linked to a loadcell; a pulley is fixed on the handle. A dc motor (Motor 1) with encoder is applied to generate torque feedback. A pulley which is couple to the upper one is fixed to the axle of the motor. All these parts are placed on a movement stage driven by a stepping motor (Motor 2).

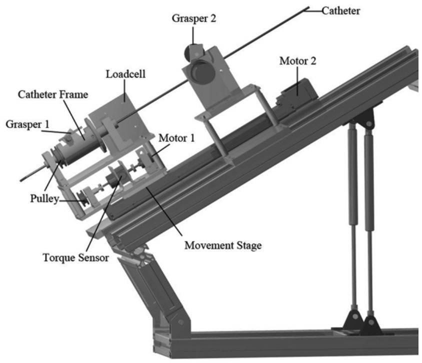


Fig.2 The catheter manipulator

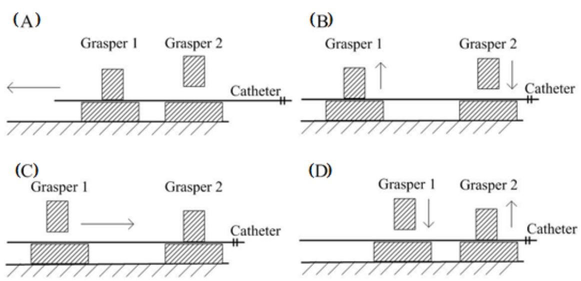


Fig.3 The inserting motions

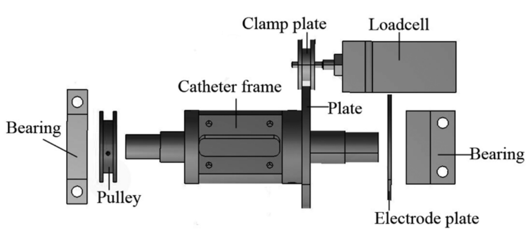


Fig.4 The force measurement mechanism

Measurement of the axial movement is realized as following. A pulling/pushing force is measured by the loadcell when the surgeon pull or push the handle, according to this pulling force, the movement output displacement to keep the handle following the surgeon's hand. Force feedback can be displaced by adjusting moving speed of the movement stage. The displacement and speed of the movement stage are sent to the catheter manipulator side, then the catheter manipulator keep synchronization with the surgeon console. When the surgeon rotates the handle, the rotation angle is measured by an encoder installed in the dc motor. The dc motor is working in the current control mode to generate the damping to the surgeon. The damping is calculated by the torque information from the catheter manipulator side.

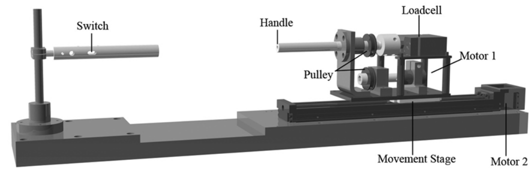


Fig.5 The structure of the surgeon console

The structure of the surgeon console is as well as the catheter manipulator; it means that the catheter manipulator could keep the same motions with the surgeon's hand. The operation will become visualized and easy to begin. On the other hand, this structure can realize the mechanical feedback to the surgeon. Our novel robotic catheter operating system perfectly solves the operating precision of surgeon, which is not well solved in the previous device, and the precision of inserting operation is 0.003mm. Another advantage of the developed system is that the operations in the master side accord with the custom of surgeon's operations in actual surgery. Consequently, we proposed a new image transmission method for surgical assistance based on the master-slave robotic catheter operating system.

III. Method and Implementation

A problem encountered in teleoperative surgery is the delay in the transmission of information from the surgery site to the operation site. In the case of teleoperative surgery, the time delay that the operator experiences is calculated as (Time delay) = (Transmission delay of control signal from the master site to the slave site) + (Response of slave) + (Transmission delay of image or force from slave to master). Although the length of the time delay depends on the configuration of the network used for the operation, it can reduce the time delay of image information and synchronize the time difference between force and visual feedback effectively using our approaches. The overall structure can be described as below.

A. The Implementation Method at the slave side

At the slave site, a digital camera capturing images at 30fps has been used to obtain images as the catheter is inserted into the EVE (Endo Vascular Evaluator Model) model. The images obtained from this camera are similar to X-ray fluoroscopic images in terms of contrast and frame capture rate. However, X-ray fluoroscopic images have a much higher resolution as compared to the images obtained from the camera. At the same time, the images were processed using a novel real-time algorithm to track the tip of the catheter to get the coordinate values in the Cartesian coordinates and we set the top-left point as the original point. Then the coordinates are sent to the master side. The size of coordinates is much less than that of image information. The real-time algorithm of motion tracking as showed in **Fig.6** below.

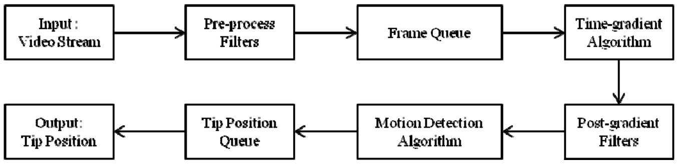


Fig.6 The structure of the surgeon console

The video stream consists of a stream of frames grabbed by the camera at 30fps. All frames are time-stamped. The pre-process filter block consists of a set of filters for suppressing noise, masking the image and improving the contrast of the image by adaptive thresholding. The frame queue is an image buffer structure managed by the queue manager block. This queue provides the appropriate input for the time-gradient algorithm. The time-gradient algorithm takes time gradients of the images in the frame queue. As the insertion speed is finite and limited, it concentrates on a neighborhood of the previous valid catheter tip position to limit the search area and decrease the processing time. The post-gradient filters suppress the noise in the gradient image and make it useful for the motion-detection algorithm. The motion-detection algorithm extracts the linear speed vector of the catheter (along the catheter axis) as well as the tip position. It also generates a true/false flag called motion flag which is true when any motion is detected. The signals generated by the motion detection algorithm are fed back to the master side.

B. The Implementation Method at the master side

At the master side, we used Canny edge detection algorithm to get the navigation chart, which is similar to the actual navigation chart in the real operation, from EVE model. The positions of the tip of catheter were reconstructed in the navigation chart according to received coordinate values from the slave site. The navigation chart was also defined in Cartesian coordinates. The canny edge detection algorithm was developed by John F. Canny as a means to detect edge lines and gradients for the purpose of image processing. This algorithm provides good detection and localization of real edges while providing minimal response in low noise environments. This algorithm is well known and explained in any introductory text on image processing. The main stages of the Canny Algorithm are as follows: Noise reduction by filtering with a Gaussian blurring filter; determining the gradients of an image to highlight regions with high spatial derivatives; relate the edge gradients to directions that can be traced; Tracing valid edges; and Hysteresis thresholding to eliminate breaking up of edge contours.

IV. EXPERIMENTAL RESULTS

To testify the accuracy of our method, we operated the handle of master manipulator to insert or rotate catheter, throughout the aortas located in the slave side of the master-slave catheter operating system, as showed in **Fig.7**, using Endo Vascular Evaluator Model (EVE) to simulate blood vessels and load cell, as shown in **Fig.7**. EVE model is made of a special silicone that recreates the elasticity and friction of human vasculature, simulating the sensation and behavior of catheter manipulation. The bending angles and radii of the tubes and the elastic and damper coefficient in the EVE are close to those of human arteries. So it can be used for blood vessel simulation.

At the same time, the controlling instructions are transmitted to the slave side. The controller in slave side can insert or rotate catheter according to the controlling instructions from master side. Meanwhile, the motion tracking program running in the slave side capture the coordinate values of the tip of the catheter and transmit the coordinates to the master side. **Fig.8** shows the coordinates of the tip of the catheter in the slave side. These coordinates are used for the correction of the tip of the catheter in the master side. **Fig.9** shows the path in the navigation chart according to coordinates received from slave side.

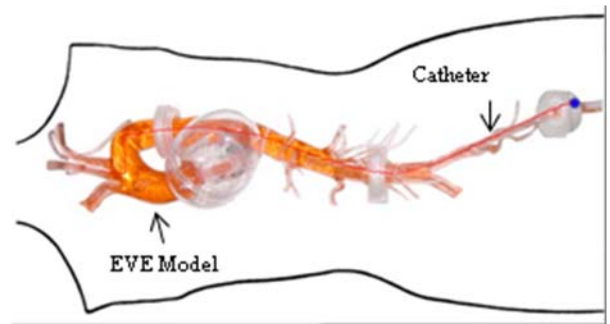
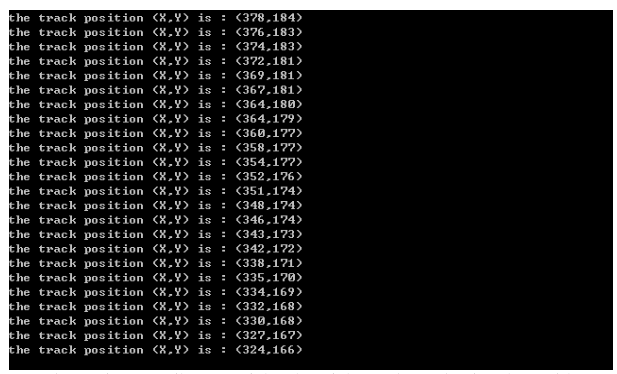


Fig.7 The path of the tip of the catheter in the slave side



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the track position (X,Y) is : (378,184)
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the track position (X,Y) is : (332,168)
the track position (X,Y) is : (330,168)
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Fig.8 The coordinates of the tip of the catheter in the slave side

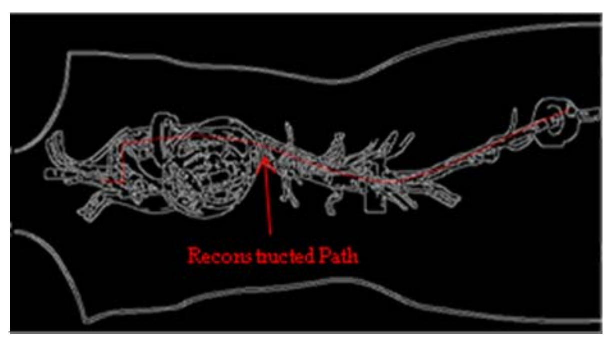

Fig.9 The reconstructed path of the tip of catheter in the master side

We can see that the path in the master side is similar to the actual path in the slave side. And the information needed to transmit is just the coordinates which is much less than image information.

V. CONCLUSION AND FUTURE WORK

The objective of this work was to develop a reliable way to reduce the time delay of image transmission and the time difference between force signals and image information. In this paper, we designed and implemented a new method that transmitting the visual information to the coordinate's values. In the slave side, the coordinates are obtained in real-time, and recovered in the navigation chart in the master side. Therefore, doctors can see the position of the catheter in real-time. Through our method, the size of image information is almost equal to force signals and controlling instruction.

At present, we just realized this method in two-dimension space. However, we will implement this technology in three-dimension based on the virtual reality environment in the future.

ACKNOWLEDGMENT

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