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Internet based Remote Control for A Robotic Catheter Manipulating System

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***Abstract*—Endovascular intervention is expected to become increasingly popular in medical practice, both for diagnosis and for surgery. Accordingly, researches of robotic systems for endovascular surgery assistant have been carried out widely. Robotic system takes advantages of higher precision, can be controlled remotely etc. In this paper a novel robotic catheter manipulation system is presented. The developed system consists of two parts, one is the controller and the other one is the catheter manipulator. The controller is designed to simulate the surgeon's operating procedure, and the catheter manipulator takes the same movement motion with the controller. A internet based communication between the controller and the catheter manipulator has been build. A server client structure is employed to realize the communication. Two-way remote control experiments are carried out between China and Japan.**

***Index Terms*—Catheter manipulation system, Remote control**

I. Introduction

Endovascular intervention is expected to become increasingly popular in medical practice, both for diagnosis and for surgery. However, as a new technology, it requires a lot of skills in operation. In addition, the operation is carried out inside the body, it is impossible to monitor it directly. Much more skills and experience are required for doctors to insert the catheter. In the operation, for example the catheter is inserted through patients' blood vessel. Any mistakes would hurt patients and cause damages. An experienced neurosurgery doctor can achieve a precision about 2mm in the surgery. However, the contact force between the blood vessel and the catheter cannot be sensed. During the operation an X-ray camera is used, and long time operation will cause damage to the patient. Although doctors wear protecting suits, it is very difficult to protect doctors' hands and faces from the radiation of the X-ray. There are dangers of mingling or breaking the blood vessels. To overcome these challenges, we need better technique and mechanisms to help and train doctors. Robotic system takes many advantages of higher precision, can be controlled remotely etc. However, compared with hands of human being, none of a robotic system could satisfy all of the requirements of an endovascular intervention. Not only because the machine is not as flexible as hands of human being but also lacks of touch. In any case, robotic catheter manipulation system could provide assistant to surgeons in the operation, but it has a long way to go to replace human being.

A lot of products and researches are reported in this area. One of the popular products is a robotic catheter placement system called Sensei Robotic Catheter System supplied by Hansen Medical[1-3]. The Sensei system provides the physician with more stability and more force in catheter placement with the Artisan sheath compared to manual techniques, allows for more precise manipulation with less radiation exposure to the doctor, and is 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 [4]. This system has a robotic sheath to steer catheter which is controlled at a nearby work station, in a manner similar to the Sensei system. The first human trail of this system was in April 2010 in Leicester UK, where it was used to ablate atrial flutter. Magnatecs Inc. produced their 'Catheter Guidance Control and Imaging' (CGCI) system [5]. This system has 4 large magnets placed around the table, with customised catheters containing magnets in the tip. The catheter is moved by the magnetic fields and is controlled at a nearby work station The Stereotaxis Inc. developed a magnetic navigation system: the Stereotaxis Niobe [6]. 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 patient table to produce a controllable magnetic field. Yogesh Thakur et al. [7] developed a kind of remote cahter navigation system. This system allowed the user to operate a catheter manipular with a real catheter. So surgeon' s operative skills could be applied in this case. The disadvantage of this system is lack of mechanical feedback. T. Fukuda et al.[8] at Nagoya University proposed a custom linear stepping mechanism, which simulates the surgeon's hand movement. Regarding

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these products and researches, most concerns are still the safety. Force information of the catheter during the operation is very important to ensure the safety of the surgery. However, measurement of the force on catheters is very hard to solve in these systems. A potential problem with a remote catheter control system is the lack of mechanical feedback that one would receive from manually controlling a catheter [1, 10-15].

In the past, we developed a robotic catheter manipulating system(RCMS)[16], the system takes good operability and precision. The system consists of two parts, one is the controller for surgeons and the other parts is the catheter manipulator. In this paper, a internet based remote control method is developed for the developed robotic catheter manipulating system. The paper is organized as following. the mechanical system will be described. The third section presents the internet based control method for the system, in section IV experiment and results will be given. The last part is the conclusions and future work.

II. System describtion

The system is designed with the structure of master and slave. The controller of the system is the master side and the catheter manipulator is the slave side. Moving mode of the catheter manipulator is designed as well as the controller. The movable parts of controller and manipulator keep the same displacement, speed and rotation angle, therefore, the surgeon could operate the system smoothly and easily. Each of controller side and catheter manipulator side employs a DSP (TI, TMS320F28335) as their control unit. A internet based communication is build between the controller and the catheter manipulator. The controller side sends axial displacement and rotation angle of the handle to the catheter manipulator. At the same time the catheter manipulator sends force information to the controller side. Serial communication is adopt between PC and control unit of the mechanism. The baud rate of the serial is set to 19200. Fig. 1 shows the robotic catheter operating system.

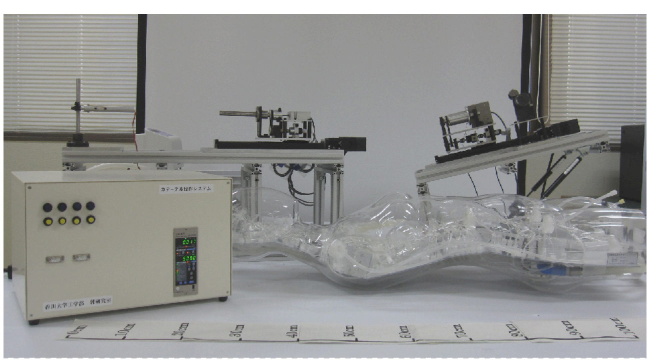

Fig. 1. Robotic Catheter Manipulating System

A. Controller of the RCMS - Master

Fig. 2 shows the controller of the system. The controller is the master side of the whole system and is placed in the surgeon side. Surgeons carry out operations by using the controller. A switch placed on the left handle is used to control these two grasper in catheter manipulator side; only one switch is enough because the catheter is clamped by one grasper at the same time. Operators'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 controller. The right handle can measure two actions of the surgeon's hand, one is axial movement and the other one is radial movement. The handle is sustained by a bearing, and is linked to a loadcell; a pulley is fixed on the handle. An 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).

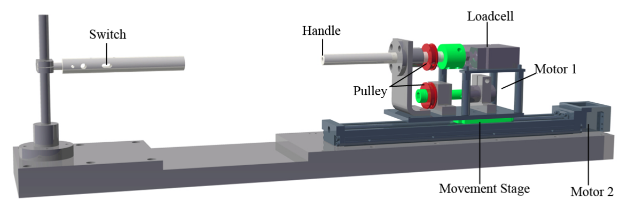

Fig. 2. Controller - Master

Measurement of the axial movement is realized as following. A pulling/pushing force is measured by the loadcell when the operator 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 send to the catheter manipulator side, then the catheter manipulator keep synchronization with the controller.When the operator 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 generates the damping to the surgeon. The damping is calculated by the torque information from the catheter manipulator side.

The structure of the controller is as well as the catheter manipulator; it means that the catheter manipulator could keep the same motion with the operator' 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.

B. Catheter Manipulator of the RCMS - Slave

Fig. 3 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 radial movement. Two graspers are placed at this part. The surgeon can drive the catheter to move along both axial and radial 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. 4.

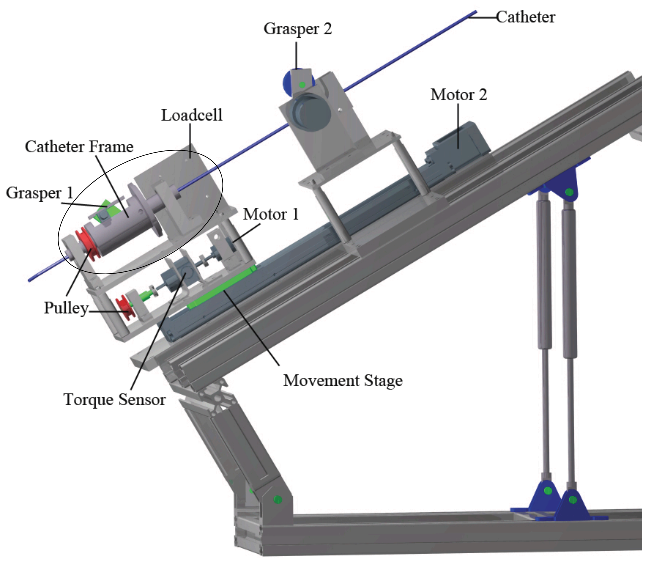

Fig. 3. Catheter Manipulator - Slave

To realize axial movement, all catheter driven part are placed and fixed on a movement stage(the green plate under motor 1 in Fig. 3). The movement stage is driven by a screw which is driven by a stepping motor(motor 2 in Fig. 3). On the other hand, a DC motor(motor 1 in Fig. 3) is employed to realize the radial 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 fix on the frame by grasper 1.

III. Remote Control System

A internet based remote control system is build. Fig. 5 shows the schematic diagram of the communication. A server-client structure is used to realize the communication. In the communication system, server could be built in each side of the robotic catheter manipulation system. Two kinds of data are transmitted between server and client, one is the control data between master and slave. In this part, rotation degrees of the handle and moving displacement of the movement stage will be sent to the slave side from

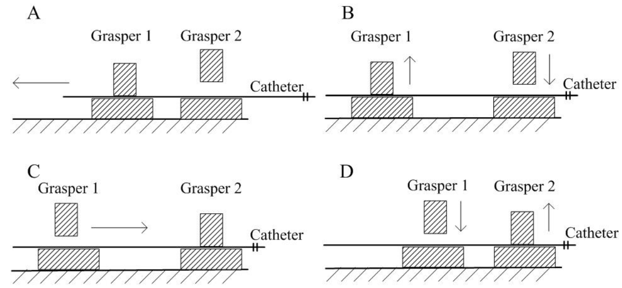

Fig. 4. Insertion process

master side. At the same time, rotation degrees of the catheter ,moving displacement of the movement stage, force data from the loadcell and torque data from the torque sensor will be sent to the master side. The other kind of data is image data. Compared with control data, the amount of image data is very large. To keep the safety of the operation, these two kinds of data are transmitted separately. IP camera are employed to get and transmit the image.

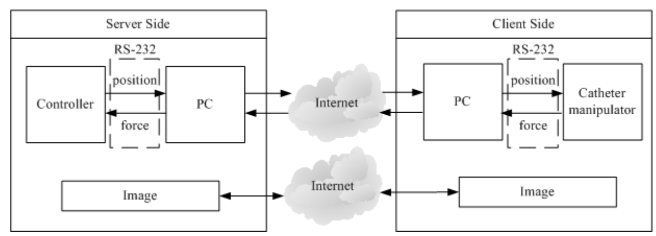

Fig. 5. Schematic Diagram of the Communication

IV. Experiments

Two remote control experiments were carried out. In these experiments, two sets of the developed system were used. Each set includes one controller(master) and one catheter manipulator(slave). One set was placed in Beijing, China and the other one was placed in Japan. A optical fiber sensor was used to monitor the contacted force between the catheter and the blood vessel.

A. Master in Japan

Fig. 6 shows the experiment system. In this experiment, the controller of the system(master) is placed in Takamatsu, Japan, and the catheter manipulator(slave) is placed in Beijing, China. The server was build in the master side(Japan). The user could see the position of the catheter from the screen. In this experiment, our target was to insert the catheter to a goal position. The displacement of the controller and the catheter manipulator are kept. Contact force was also kept. Fig. 7 shows the position tracking trajectory of the axial direction. From the experimental result it could be found, the slave can follow the master very well. However, because of the time delay, errors between the two side are generated.

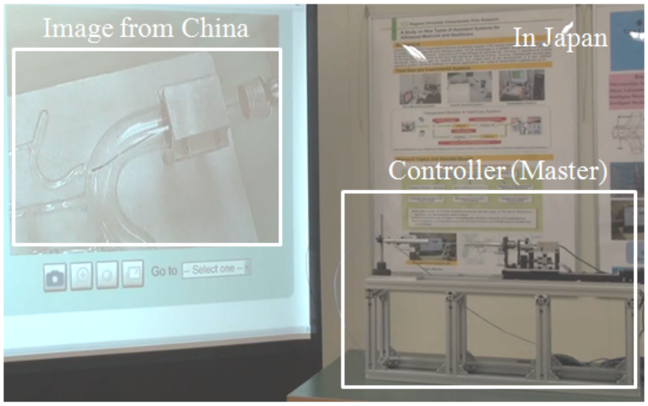

Fig. 6. Experimental System

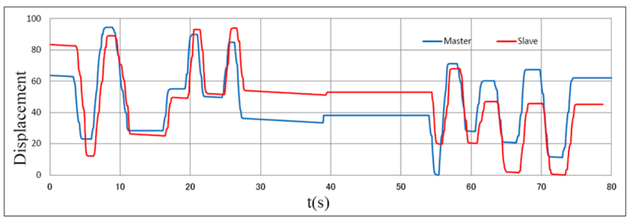

Fig. 7. Tracking trajectory of the axial direction

B. Slave in Japan

Fig. 8 shows the second experiment. The catheter manipulator of the system(slave) is placed in Takamatsu, Japan, and the controller(master) is placed in Beijing ,China. In this experiment, a human body model is used. The target was insert the catheter from the leg to the brain with the developed system. As the same as the last experiment, the server was built in Takamatsu, Japan. Fig. 9 shows the position tracking trajectory of the axial direction.

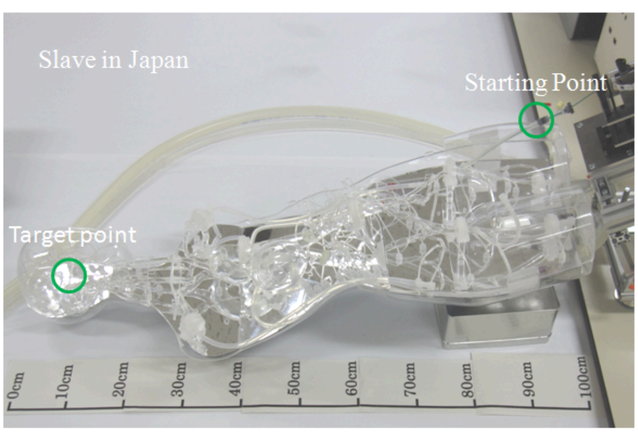

Fig. 8. Experimental System

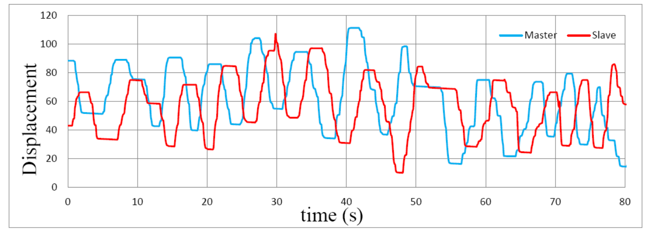

Fig. 9. Tracking trajectory of the axial direction

V. Conclusion

We proposed a robotic catheter robotic manipulator. The system contains two parts, the controller and the catheter manipulator. These two parts have the same movement motion. With this kind of design, the operating procedure becomes visualized. The operating motion is similar to the actual motion of the surgeon' s hand. At the same time, with this structure, mechanical feedback could be realized. A internet based communication system was built between the controller and the catheter manipulator. Both control data and image could be transmitted by the communication system. To keep the safety and improve the correct rate of the data, the control data and image data are transmitted separately. Two remote control experiment were carried out. Two-way remote control were realized between China and Japan. Experimental results indicated that the slave can follow the controller very well. However, error were generated caused by the time delay of the network.

In the future, communication algorithm will be developed to reduce the tracking error between controller and the catheter manipulator when using internet based remote control. And a danger avoid system based on the sensor installed on the catheter will be realized.

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