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A Force Acquisition Method in A Catheter Navigation System

Yuan Wang*, Kangqi Hu, Nan Xiao and Shuxiang Guo
The Institute of Advanced Biomedical Engineering System
Beijing Institute of Technology
Email: wangyuan24@foxmail.com

***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 catheter navigation systems are with advantages of higher precision, can be controlled remotely etc. However, the haptic feelings, the important function for propelling robotic catheter navigation system is immature. In the paper, a robotic catheter navigation system is proposed. The navigation system is designed to simulate the surgeon Õs operating procedure. And the haptic feedback issue is concerned. A clamping force measure method is developed. Therefore, surgeons can carry out operation with their own skills. System implement and performance are presented.**

***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.

Products and researches are reported in this area. One of the popular products is a robotic catheter navigation system called Sensei Robotic Catheter System supplied by Hansen Medical [1]. 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. The Stereotaxis Inc. developed a magnetic navigation system: the Niobe [2]. 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. Catheter Robotics Inc. has developed a remote catheter system called Amigo [3]. This system has a robotic sheath to steer catheter that is controlled at a nearby workstation, in a manner similar to the Sensei system. Yogesh Thakur et al. [4] developed a kind of remote catheter navigation system. This system allowed the user to operate a catheter manipulator 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. [5] at Nagoya University proposed a custom linear stepping mechanism, which simulates the surgeon's hand movement. Regarding 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 [6-10].

Our group has developed kinds of robotic catheter navigation system in resent years. A wheel-driven catheter manipulator was made [11] [12]. In the system, phantom omni was employed as the surgeonąŕs console. Force sensors are installed on the end-tip of the catheter. In the system user can monitor force information by using monitors. However, compare with some other system problems of this system are poor operability and lacks of vivid haptic feedback [13].

In order to improve these existed problems we developed a novel robotic catheter navigation system that imitates surgeonąŕs action to operate catheter [14]. Surgeonąŕs console is proposed. With the system dexterous operation and good operability can be achieved. On the other hand, force feedback is a major concern of this system. Implementation of the force feedback contains two key technique issues, force measurement and haptic implement. Additionally, compactible virtual reality environment is made as an assistance system to help users carry out their procedure [15].

In this paper, a measurement method of the catheter manipulation force is proposed. The remainder of this paper is organized as follows. In the next section the developed system is introduced. Following that, in Section III measurement of catheter manipulation force is discussed. The next section is the experiments and section V presents concluding remarks.

II. The catheter navigation system

In the catheter-based operation, there are two basic motions of the catheter, rotation, and go forward and backward. Therefore, the surgeon could finish an operation just by operating the catheter with these two basic motions. Figure 1 shows the surgeonąŕs actions during inserting motion. We developed the system to imitate this procedure as shown in Figure 2. The surgeonąŕs console is placed on the left and the catheter manipulator on the right.

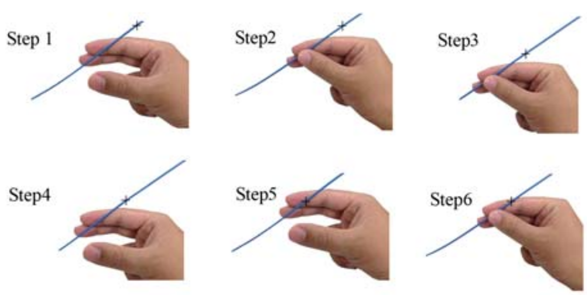


Fig. 1: Insertion process of the catheter

In a real operation procedure, surgeon inserts the catheter to the lesion based on the handąŕs feeling and the DSA image. For example, the surgeon rotates the catheter when he/she feels more resistance from the catheter. Haptic is the essential element for surgeons to finish operations.

A. The catheter manipulator

The catheter manipulator is shown in Figure 3. We designed this mechanism with imitating surgeonąŕs hands. Grasper 1 in figure 3 is using for fixing catheter on the cylinder playing the role of the thumb in Fig. 1. One can operate the catheter to insert and rotate when the catheter is fixed on the cylinder with grasper 1. And one can drive the mechanism go backward without disturb the catheter by lifting up grasper 1 and putting down grasper 2.

A Maxon dc motor coupled to the cylinder drives rotation of the catheter. The translation is driven by a movement

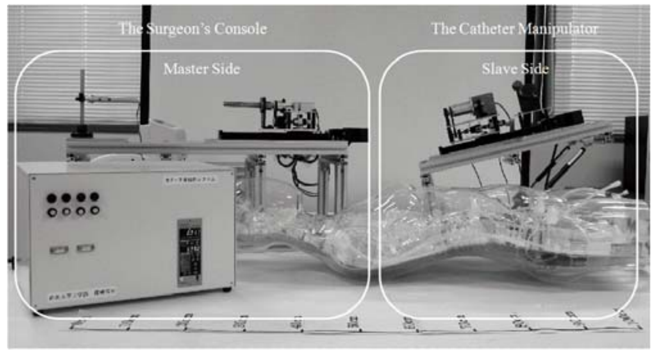


Fig. 2: The catheter navigation system

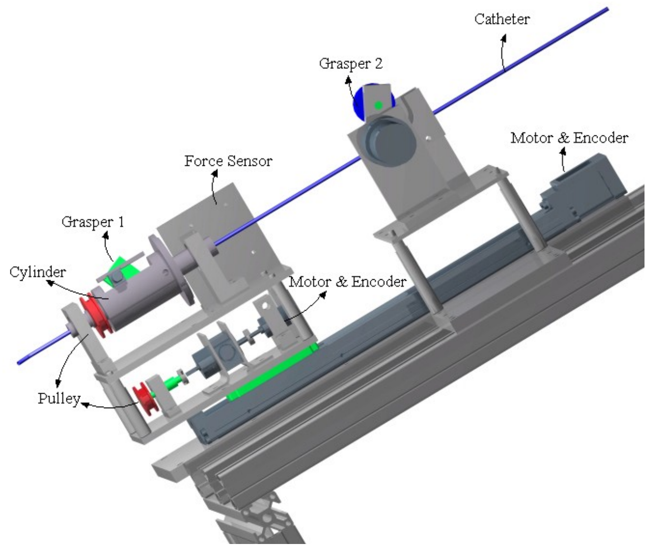


Fig. 3: The catheter manipulator

stage also connected to the cylinder. Control of the system is realized by a digital controller (TI, TMS320F28335). In the future a more compact structure that will keep a same action principle will be developed.

B. The surgeon's console

Figure 4 shows the developed surgeon's console. Surgeons can input their control commands to the catheter manipulator and get haptic feedback. Parts are placed on a slide stage that is driven by a motor with encoder. The handle is linked to a force sensor, and the linkage of the joint is painted green in figure 4. Pushing/pulling force can be measured when we operate the handle in the axial direction. The slide stage is programmed to follow userąŕs hand based on the dragging force. Force feedback is achieved by control the mechanical impedance of the handle when the surgeon drags the handle in axial direction. The sensed force from the catheter manipulator side decides impedance of the handle. Displacement of the handle is measured with an encoder coupled to the motor on the slide stage. In addition, one button is placed on this part to control graspers at the catheter manipulator side. (Only one grasper keeps compress at the same time, therefore, one button is enough for control of two graspers.) Users can twist the handle freely in radial direction and we coupled the handle with a motor by pulleys and a belt as shown in figure 4(red parts), and the encoder will measure rotation angles. The rotation action will not disturb translation and vice versa. At first we plan to generate a haptic feedback in radial direction but until now we didn't implement it and we will not discuss it in this paper. It may be carried out in the future if necessary.

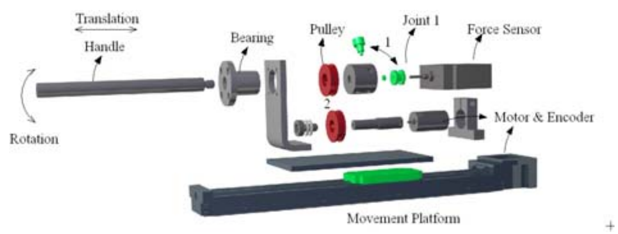


Fig. 4: Structure of the interface: The surgeon can pull, push and rotate the handle to input their control commands just like operating a catheter. Motions measured by the device will be sent to a remote catheter manipulator or a virtual environment.

Control of the system is also achieved with a digital controller (TI, TMS320F28335, 150MHz). Communication between the catheter manipulator and the surgeonąŕs console is achieved by RS485. Time delay is less than 1ms because of a small quantity of data and a high-speed transport protocols (serial peripheral interface). Beside communication with the catheter manipulator, data is also transmitted to a PC via RS232 serial communication. Performances of the mechanical system have been evaluated in [15].

III. Clamping force measure

A. Hardware design

When the catheter is fixed to the cylinder and driven move forward or backward the axial resistance on the catheter could be measured. The measurement structure is shown in Figure. 5. Two pieces of hard rubbers are placed inside the cylinder of Figure 3. Grasper 1 can put up and down rubber-A and rubber-B is connected to a force sensor that is fixed on the cylinder. The catheter can go through the cylinder freely when rubber-A is put up as shown in Figure 5 a). And the catheter is blocked in the groove when rubber-A is put down as shown in Figure 5 b). We can get an enough block force by modifying the radian of the groove. Axial resistance of the catheter will act on rubber-A and rubber-B. Hence, the force sensor that is connected to rubber-B obtains resistance on the catheter. This force can represent the actual stress on the catheter as surgeon feels with hand because of the linear structure.

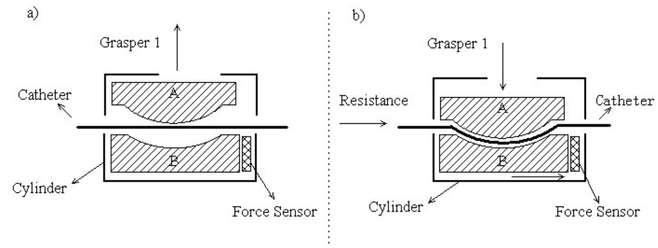


Fig. 5: Measurement structure of the clamping force on the catheter.

The sensor needs to be installed inside the cylinder. In order to keep the structure compact a pressure sensor is employed here instead of a force sensor. As a consequent the area of the sensor needs to be considered.

B. Method

An insertion experiment was carried out to evaluate the performance of the developed measurement structure. The experimental setup is as shown in Figure 6 a). In the experiment we use the catheter manipulator to drive the catheter go throw a damper that is fixed to a load cell. The clamping force on the catheter is measured by the developed mechanism. Figure 6 b) shows the damper. Damping force is adjusted to a proper magnitude by which the catheter can move smoothly.

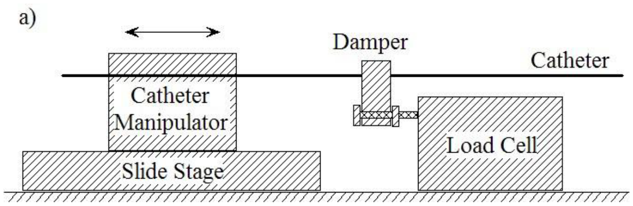
The translation moving speed of the catheter manipulator is set from 1mm/s to 10mm/s with a 1mm/s interval, and from 10mm/s to 50mm/s with a 5mm/s interval. In general most of the operations can be carried out in that range. A pci compatible AD converter is used to acquire the experimental data. The sampling frequency is set to 1kHz. At each speed, 10,000 samples are kept. The error Čã between the measures of load cell and the catheter manipulator are defined by:

$$\sigma = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(f_{si} - f_{ri})^2} \tag{1}$$

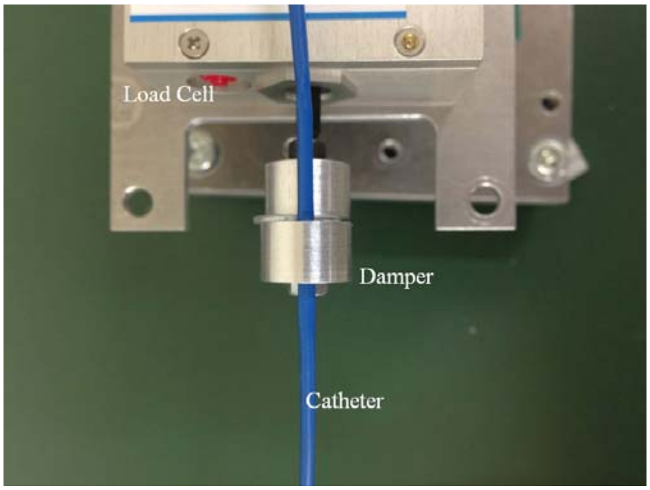
where N is number of total samples, f_s and f_r are the force measured by the catheter manipulator and the load cell.

C. Results

Figure 7 shows the insertion experimental results. The insertion speeds are 1mm/s, 5mm/s, 10mm/s and 20mm/s. fs and fr are the forces measured by the catheter manipulator and the load cell. σ is the error between these two forces which is defined by equation 1. Displacement of the catheter manipulator varies due to the fixed sampling time and different speed.



(a) Schematic Diagram



(b) Damper

Fig. 6: Experimental setup

IV. Conclusion

A haptic surgeonąŕs console and corresponding catheter manipulator were presented in the paper. The surgeonąŕs console simulates motions of surgeonąŕs hand to input control command and out force to the user. The corresponding catheter manipulator could follow the surgeonąŕs console with a same motion to insert a catheter into the blood vessel. A novel catheter clamping force measure method was proposed. The method is suit for the developed catheter navigation system. It can achieve a high accuracy when the translation speed is smaller than 50 mm/s. Therefore the first part towards the haptic problem has been achieved. In the future, force feedback will be implemented through the developed surgeonąŕs console.

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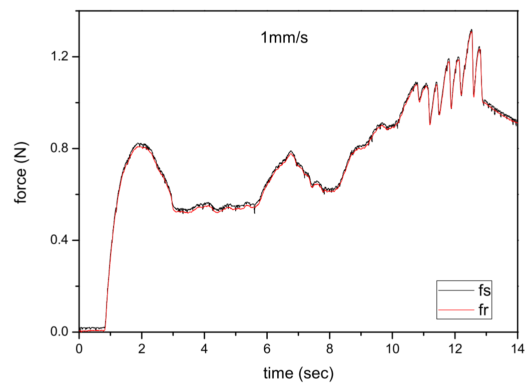
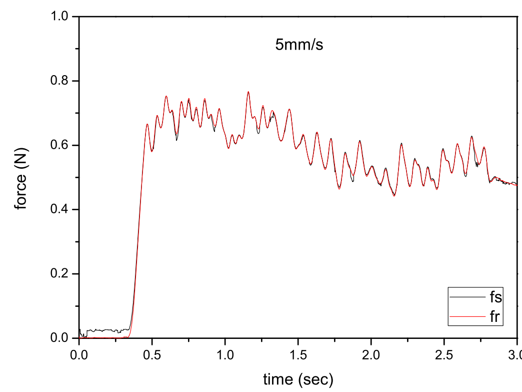


(a) 1mm/s



(b) 5mm/s

Fig. 7: The experimental Results

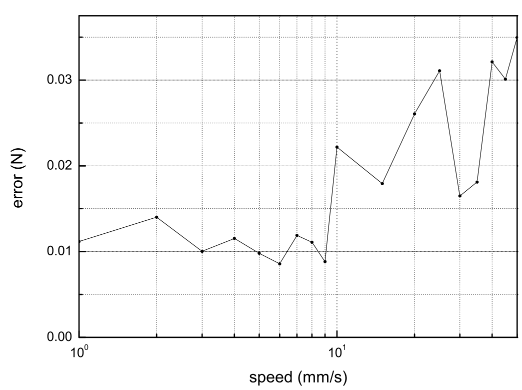


Fig. 8: Statistics of the experimental results.

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