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Motion Characteristic Evaluation of a Catheter Operating System Using an Optical Mouse Sensor

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***Abstract* - Endovascular intervention is expected to become increasing popular in medical practice, both for diagnosis and for surgery. Accordingly, researches of robotic catheter operation systems for endovascular surgery have been studied widely. The master-slave system is adopted by some researchers in this area. The catheter operating system consists of two parts, one is the master system (surgeon console), and the other is the slave system (catheter manipulator). In order to improve maneuverability of the catheter operating system, the master system is designed to imitate the surgeon's operating procedure and skills as well as operating the clinical catheter, the slave system carry out the same motions with the master side. In this paper, a new catheter motion measurement device based on an optical mouse sensor is presented. Finally, some of catheter motion measurement experiments have been done to verify the dynamic performance of motion measurement device in the master system. Therefore, the motion measurement device in the master system can meet the needs of training the novice surgeon.**

Index Terms –minimally invasive surgery, robotic catheter operating system, optical mouse sensor, motion measurement

I. INTRODUCTION

Minimally invasive surgery (MIS) is a revolutionary surgical technique, in which surgeries are performed through robotic surgery system. The main advantage of this technique is that the amount of trauma involved in MIS is far less than in conventional surgery because the incision is very small, result in reducing the patient recuperation time and the burden of long time hospital stay and surgery fee [1]. However, these techniques require a lot of skills in operation. In addition, the operation is carried out inside the body, it is impossible to monitor it directly. Before the operation, the novice surgeons need to train a long time to complete this operation. For example, the catheter is inserted through the blood vessels. Any mistake would hurt the patients and cause damages [2-19]. Except this, during the operation, the current procedure, which involves manual intervention by a human operator, has some drawbacks, which include: the first is prolonged X-ray exposure for the patient and the surgeon. The second is difficult to control precisely the proximal end of the catheter in catheter ablation [20]. In order to solve these problems, robotic system was adopted by many researches. Robotic system has some advantages, such as controlled remotely and protecting form radiation. However, none of a robotic system could satisfy all of the requirements during the operation, compared with the hands of human being. The robotic system only is used as an assistant device to surgeon during the operation, because it is not as flexible as the human being. So the accurate motion measurement in the master side is very important.

According to physical characteristics of the capacitive, inductive, magnetic, ultrasonic and optic, all kinds of displacement sensors have been designed and applied into position and velocity measurement. Some of sensors are able to provide measurements with sub-meter accuracy. Nevertheless, not all the application needs such high measurement accuracy. In addition, the higher measurement accuracy sensors, the cost is more.

In 1999, the first optical mouse was unveiled by Agilent Technologies [21]. Now, the optical mouse is accepted as a major pointing device for the computer. With the development of the technology, the price of the mouse is about $30. The use of the computer optical mouse for scientific research has been previously reported. A device with three optical mice was used for tracking minimally invasive surgical instruments in training setups [22]. The optical mouse has been applied in a two-dimensional displacement measurement [23]. Recently, optical mouse sensors have been utilized to measure the position and orientation of a mobile robot [24]. The optical mouse sensor with the short distance image acquisition capabilities is presented as a counterfeit coin detector applied to the two-Euro case [25]. According to the sequential surface images acquired by the optical mouse sensor, the direction and magnitude of movements can be measured. So it can be used as an incremental rotary encoder [26]. In this paper, the master-slave system is adopted in catheter minimally invasive surgery. In the master side, the motion measurement device is designed. The optical mouse senor is used to measure the motion of the catheter, because of the optical mouse sensor with the same characteristics with the mechanical mouse. The mechanical mouse has two rollers located within the mouse, one of the rollers is used to detect the x-direction motion, whereas, the other detects the y-direction motion. During the catheter minimally invasive surgery, two degrees of freedom mechanism was designed to ensure the safety of the surgery. One degree is catheter insertion or extraction movement, the other degree is used to rotate the catheter. When the catheter was inserted into the branch of the blood vessel, it is difficult to insert the catheter, the direction of insertion can be changed by rotate the catheter.

This paper is organized as follows, In section II, the master system and the motion measurement device based on an optical mouse sensor was described. In section III, the catheter insertion and rotation dynamic performance evaluation experiments have been done by using the stepping motor with different frequency motion as reference input signal. The conclusions and future work are given in section IV.

II. System Design

In generally, a teleoperation surgical system as shown in Fig.1 consists of master system (console) and slave manipulator system (executing), in which the slave manipulator tracks the motion of the master device that is commanded by the surgeon and in which the measured force fed back to the master device form the slave manipulator.

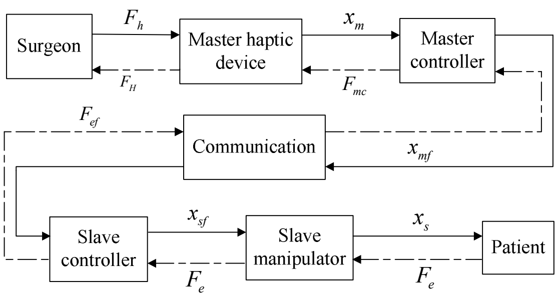


Fig.1 The master-slave system

A. The Developed Master System

In this paper, a new master system as shown in Fig.2 was proposed. The master system operated by the surgeon is placed at the console site, which consists of two parts: one is the haptic structure which is not only be used to provide the haptic sensation for the surgeon but also be used to train the novice surgeon with clinical catheter, and the other one is motion measurement structure used to measure the motion of surgeon operating the catheter, which was used as the motion control commands transmitted to the slave manipulator.

During the operation of intravascular neurosurgery, it is significant to acquire the contact force information between the catheter and blood vessel. Because the blood vessel is fragile, it is easy to damage the blood vessel during the operation. Especially, in high risk areas, a little excessive force exerted onto the blood vessel walls would lead to complications such as inflammation, thrombosis, perforation and etc. [27]. In conventional catheterization, the catheter is inserted-extracted in axial direction and rotated in radii direction directly by the surgeon, so the surgeon can obtain the contact force directly during the operation and control insertion or rotation to avoid the danger of damaging the blood vessel [28]. In order to improve the safety of the surgery, it is important to design a motion measurement device with high precision.

B. The Catheter Operating System

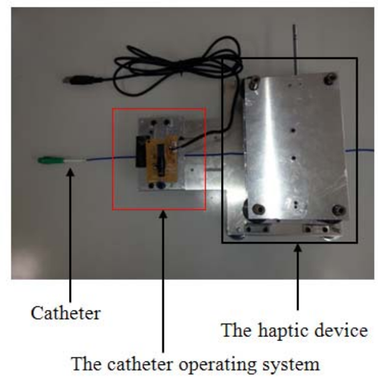
In the master-slave system, the catheter insertion (extraction) and rotation motion in the slave system is the same with the motion in the master system. The proposed motion measurement structure has some requirements.

1. Realistic manipulation of the catheter in the master side in two kinds of motion. One is catheter insertion movement along the axis direction of the catheter (1st kind of motion), the other is catheter rotation movement in radii direction of the catheter (2nd kind of motion).

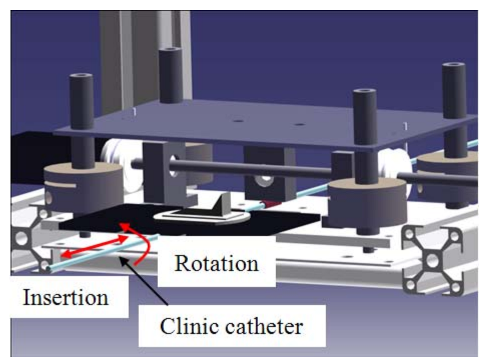
2. During the training, the no-experience surgeon can operate the clinical catheter.

3. The level of accuracy and sensitivity is suitable to do some assessment of the trainees.

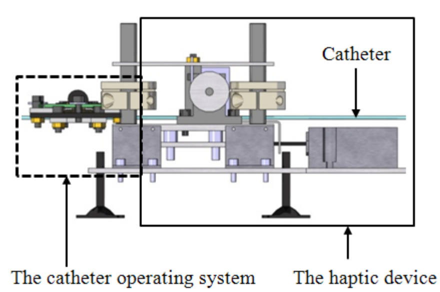
Based on the requirements, a prototype of motion measurement device is designed. In the master device , these degrees of freedom is realized by the surgeon, the surgeon operated the clinical catheter insertion (extraction) or rotation in the master side, the motion commands measured in the master side by motion measurement device were transmitted to the slave system to realize the teleoperation.



(a)The developed master system



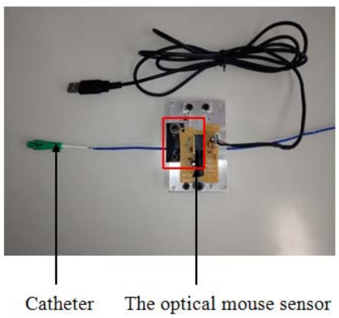
(b)The front view of the master system



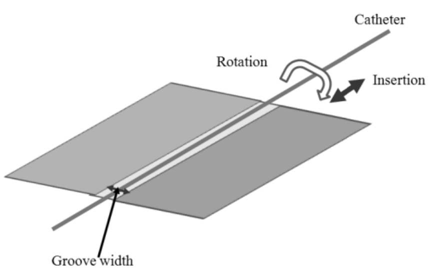
(c)The left view of the master system

Fig.2 The developed master system

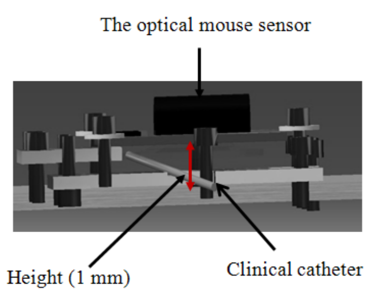
In this new catheter motion measurement structure, the optical mouse sensor is used to measure the motion of the catheter both the insertion (or extraction) direction and the rotation direction. Now, the available products that can measure the motion of the catheter are complex and expensive, some of them limit the degree of the movement. The aim of this research is to develop a new catheter motion measurement structure in master system, which has some characteristics. The first is that a new un-contact measurement method used in catheter motion structure was proposed. The second is that the clinical catheter was used to operate in the master system with benefit of providing real feel for the surgeon.



(a)The catheter operating system



(b) The scheme drawing of the catheter guide



(c)The catheter operating structure

Fig.3 The catheter operating system in the master side

The catheter motion measurement device consists of the optical mouse sensor, the metal piece used for the optical mouse sensor assembling, and the catheter. The catheter can be inserted or rotated by the surgeon easily and smoothly and guided by the groove on below metal plate as shown in Fig.3 (b) the catheter guide structure. The groove width design is according to the diameter of clinical catheter. In this paper, the width is 3mm. The size range of clinical catheter used in this device is from the 3Fr to 8Fr.

When we insert and rotate the catheter, the displacement of catheter insertion direction and rotation direction can be measured by the optical mouse sensor. The height of between the optical mouse sensor assembled plane and the catheter surface is very limit in 1.25mm to get the distinct images of the catheter. In this paper, the height was designed at 1mm to get the distinct image for the optical mouse sensor.

C. The Optical Mouse Sensor

The basic working principle of the optical mouse sensor is described in Fig.4. It consists of a single light emitting diode (LED), two optical lens, working surface and sensor. A LED is in charge of illumination the working surface at an angle. One of the optical lens is used to transmit the light from the LED to the working surface. The other lens is used to transmit the image to sensors. The optical mouse sensor works by comparing the images of the working surface that are refreshed approximately every 1500th of a second [9].

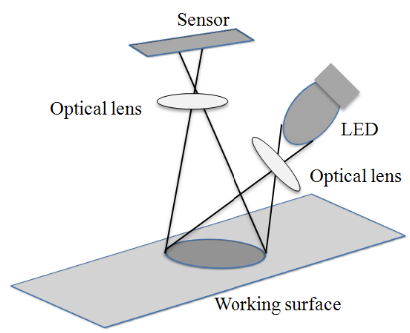


Fig.4 The schematic drawing of the optical mouse sensor

The displacement of the catheter is measured by the optical sensor by taking the sequential surface pictures of catheter with a small CCD chip at high frame rate [12]. Image of the surface are acquired via led- optical lens illuminate system and COMS image detector. The displacement values (the numbers of “counts”) of the catheter in directions of insertion or rotation generated by a digital signal processor (DSP) is sent to the computer by serial peripheral interface. The direction and magnitude of the catheter movement determines by the changes of the surface image information.

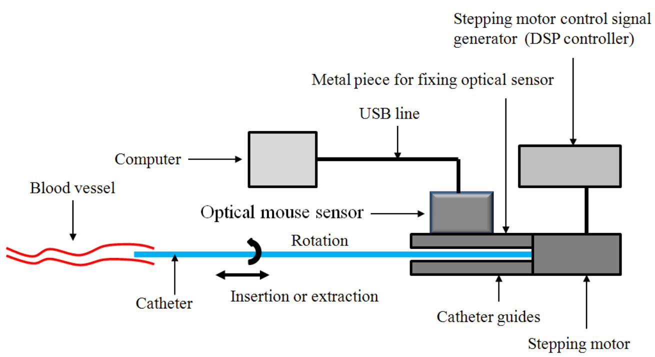
D. The Catheter Motion Measurement Method

The measure method is the same as we move the mouse when operate the computer. In computer operation, we move the mouse on the mouse pad. For example, moving the mouse along the level direction, the displacement of cursor moved on the computer screen in level direction, this kind of characteristic can be used measure the displacement of catheter insertion motion. The mouse was moved in the vertical direction in the mouse pad, the displacement of cursor moved in vertical direction, which can be used for rotation motion measurement.

III. EXPERIMENTAL RESULTS

Motion measurement evaluation system as Fig.5 shows consists of Linear Axial Actuator LX2605 (with encoder), DSP (TI, TMS320F28335) and motion measurement device. DSP controller is used to generate the PWM signal to drive the stepping motor and stepping motor was used to insert and rotate the catheter instead of operating the catheter by surgeon. The velocity of insertion (extraction) and rotation of catheter can be adjusted by change the frequency of PWM signal.

In the experiment, the catheter size of 6 Fr (2mm) used in insertion and rotation motion experiments have been done to test the dynamic performance of motion measurement structure in the master system.



(a) The schematic drawing of motion characteristic evaluation of a catheter operating system

(b)The clinical catheter (6Fr)

Fig.5 The experimental setup

A. *The Catheter Insertion Experiment*

In order to test dynamics performance of catheter insertion motion, several experiments have been down as shown in Fig.6. The different frequencies and insertion displacements were set to do the experiment. The frequency of PWM at 110Hz and the displacement was set at 25mm. In this kind of situation, the measured displacement of optical mouse sensor can't follow the stepping motor accurately. The frequency of PWM at 80Hz and50Hz the displacement was set at 45mm, he frequency of PWM is set at 40Hz, the displacement of stepping motor is set at 30mm. In these situations, the optical mouse sensor gets the good dynamic performance. The upward curve shown in Fig.6 demonstrates insertion catheter movement. And the downward curve represents extraction the catheter movement. The data measured by the optical mouse sensor was transmitted to the slave system to control the slave manipulator.

So the suitable frequency extent of catheter insertion is form 40Hz to 80Hz. The frequency of catheter insertion is the same as the speed of surgeon who operate the catheter according to the experience. When catheter advanced into the branch of blood, surgeon can operate the catheter at low frequency. Fig.7 shows the error in the case of different frequency. We can know the error is below 0.32 at frequency of 40Hz, 50Hz and 80Hz. It means the good performance can be obtained at 40Hz to 80Hz. According to the experiments, when the surgeon operated the catheter at frequency of 1 Hz -2 Hz in the insertion or extraction direction, the motion measurement device can get a good performance.

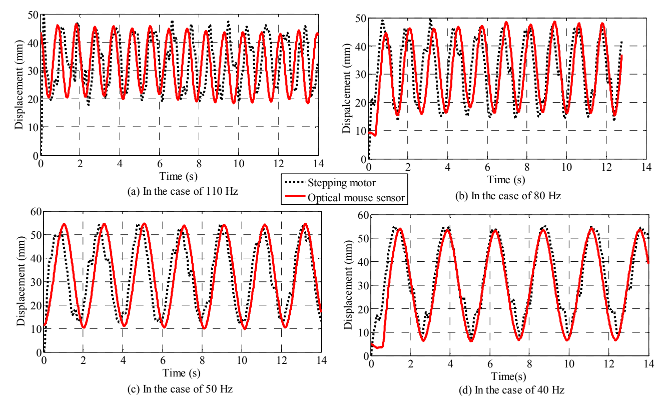


Fig.6 The catheter insertion motion measurement results in the case of different frequency

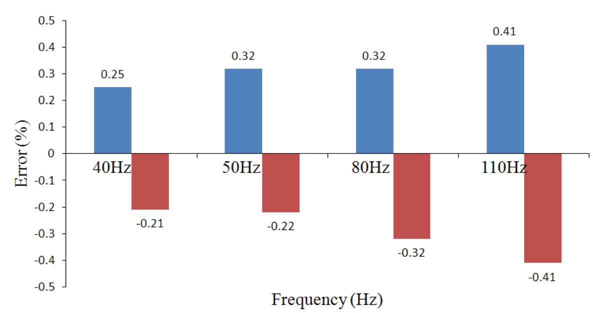


Fig.7 The error of the insertion motion measurement results in the case of different frequency

B. *The Catheter Rotation Experiment*

The same method was used in the catheter rotation experiment. Fig.8 shows the performance of the optical mouse senor and the stepping motor in the case of different frequency of rotation movement. The upward curve shown in Fig.8 demonstrates rotation catheter in the positive direction. And the downward curve represents rotation the catheter in the negative direction. The rotation data measured by the optical mouse sensor was used to control the slave manipulator, when the catheter advances difficulty.

Fig.9 shows the error results between the stepping motor and Optical mouse sensor in the rotation displacement measurement. The error is small at the frequency 40Hz. So when the catheter advanced difficulty, the catheter was rotated to insertion should be at the frequency 40Hz in this new motion measurement device.

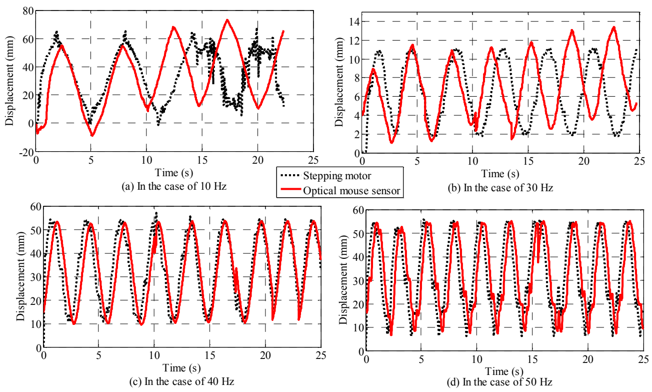


Fig.8 The catheter rotation motion measurement results in the case of different frequency

According to the experiments, when the surgeon rotated the catheter at frequency of about 0.5 Hz in the positive or negative direction, the motion measurement device can get a good performance.

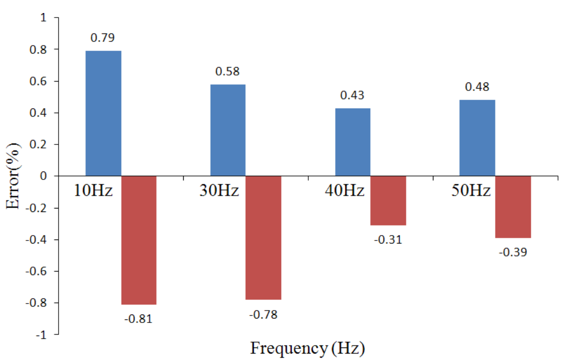


Fig.9 The error of the rotation motion measurement results in the case of different frequency

IV. Conclusions and Future Work

In this paper, a new catheter motion measurement device in master system was proposed. The optical mouse sensor was used as a motion measurement sensor in the master system to measure the displacement of catheter motion. The stepping motor was used to drag the catheter insertion and rotation instead of the surgeon's operation to measure the dynamic performance of the optical mouse sensor. Different of frequencies of insertion and rotation catheter experiments had been done to test the dynamic performance. In the catheter insertion motion measurement case, the error is small at the frequency 1Hz-2Hz. So the surgeon should adjust the insertion speed according to this frequency extent. In the rotation motion case, the good performance was obtained at the frequency of about 0.5Hz. The application of optical mouse sensor in minimally invasive surgery has been verified. So the developed master system with motion measurement device using the optical mouse sensor can be used to train the novice surgeon with clinical catheter in minimally invasive surgery.

To encounter the problem of limited visual information, the haptic device that enables manual interactions with virtual environments or teleoperated remote robotic system is proposed in the master system. During in the teleoperative system, the surgeon is far from the patient, the haptic device is used to provide the haptic sensation to the surgeon to increase the teleprensence.

During the minimally invasive surgery, for example, the clinic catheter was inserted into the blood vessel, the blood will be penetrated, when the catheter contact the blood vessel wall at the force about 0.12N. So the force-reflecting interface device (haptic interface) is need in the master system to avoid penetrating the blood vessel.

In the future, some of experiments will be done to evaluate the performance of haptic interface device in the master system. Furthermore, realize the haptic communication during in teleoperative system in minimally invasive surgery.

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