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Development of a Real Catheter-based Force Feedback System

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***Abstract*—Catheter operations are actually common in the medicine field. The development of new medical equipment becomes essential. These operations request high skills and surgeons have to be trained for operations.**

Efficients catheter manipulating systems already exist for tele-surgery but they can't create the same feeling as a classic operation. According to the needs of surgeons, this study propose a new manipulating system witch it uses a real catheter.

At first, a photographic sensor will be used to get the translation and the rotation of the catheter without friction. Then an haptic device will be designed to change the feeling of the surgeon. A stepping motor couple with a pulley system will change the pressure on the catheter and then change the manipulating feeling. At last some experiments will be done for verified the characteristics of the system.

***Index Terms*—Master-slave, Catheter system, Steerable catheter, Catheter surgery, Haptic Device, Teleoperation**

I. Introduction

A. Background

This study propose a catheter manipulating system witch can give to surgeon the real experience of catheter manipulation. In fact the state-of-art for surgeon in the teleoperation use heavy structure like the Sensei X by Hansen [1], [2] or the BD Nexiva [3]. These robots are really powerful and performant but different form the basic skills and feelings of surgeons for the catheter manipulation.

The slave side witch operated the patient has already been built [4],[5],[12],[13],[14] and is now under improvement. We are improving a new system to get better information about the friction under the blood vessels for the design of a new communication software between the slave-side and the manipulating system.

B. The real catheter-based force feedback system

The motion of the catheter is detected by a photographic sensor don't generate friction. A new haptic-device has been developed and design. The force feedback is one of the most important part of a teleoperation system because it give the feeling to the manipulator. Some haptic force feedback devices have already been developed [6] but they don't use a real catheter. This new system can change the friction on the catheter with a stepping motor couple to a pulley system. Then the pressure between the catheter and the system will change the feeling of the surgeon. If the slave side detect friction force or wall the system will generate it as near as the real blood vessels. Some researches are focus on the transparency optimization to improve the performances of the system [7], [8], [11].

II. Motion Measurement of Catheter

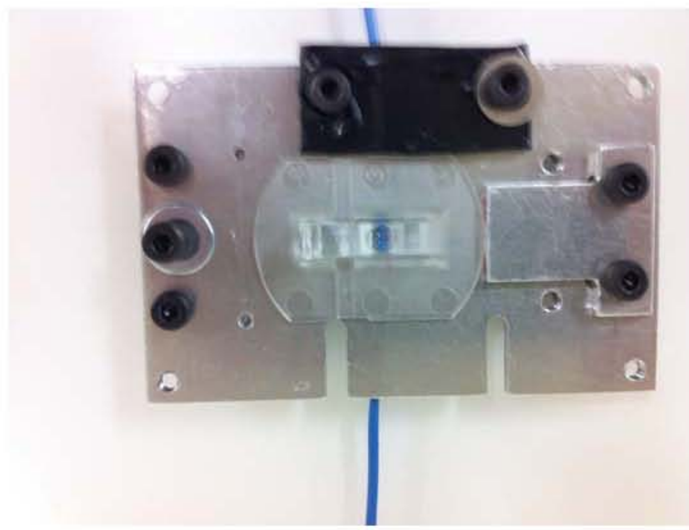

Fig. 1. Total sensor system

This new device has to be fully transparent for the surgeon [7]. That's why the motion sensor must'nt create parasite friction. The photographic sensor of a mouse computer can get datas about the position and the rotation of the catheter without contact or friction. When the mouse move, the sensor transform the irregularities of the material texture in two dimensions translations X and Y. After some experiments it was clear that a smooth catheter can't be used for this device: the sensor can't compute the motion if the catheter have an homogenous surface. We have to used streaks catheters for an optimal accuracy.

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A device has been built to drive the catheter and get data form the sensor. The electronic board is adjusted by the device and the catheter is guided by a small groove. Finally we can move the catheter easily and drive the cursor on the screen as a mouse with the sensor. The next step was create and adjust the software part. The computer write the displacement of the catheter as two translation in points, not in mm. Some experiments have been carried out to find the relation between the sensor datas and the real displacement of the catheter accorded to the next system:

$$\begin{cases} U = a.X \\ \theta = b.Y \end{cases}$$

Sensor outputs in X and Y directions, U and θ are the real displacement, a and b are two constants find by experiments. The b parameter depend on the catheter diameter. So that we used the same catheter for all the experiments in this paper. Then it's easy to get the speed and the acceleration when we get motion datas. The speed is the numeric derivate function of motion, we can calculate it with this formula:

$$Speed = \frac{U(k) - U(k-1)}{\Delta T} \tag{1}$$

Experiments have been carried out to evaluate the sensor. The accuracy depend of the photographic sensor witch can easily down under 1/10 millimeter.The catheter can be moved with without friction, the position can be recorded with high accuracy. We can also get the speed and the acceleration of the catheter for the dynamics equations.

III. The Haptic device

A. system description

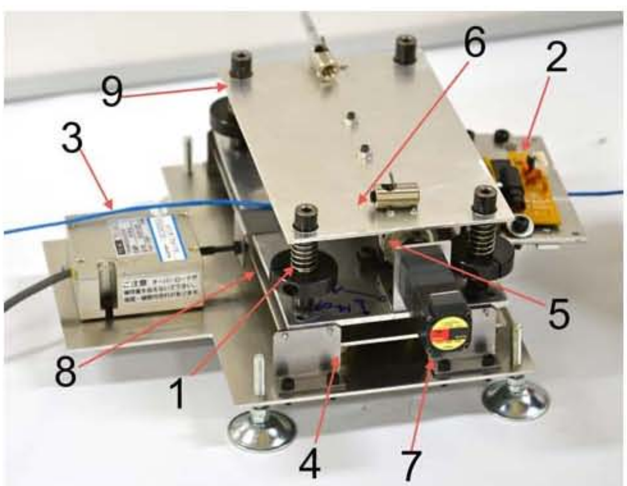

Fig. 2. Haptic device

The haptic device have to change the feeling of the surgeon during the operation. The whole structure has been designed and optimized by CAD design first. In a second time the system has been built (Fig 2) and some tests have been done. To create the haptic feedback the system uses force friction to change the speed of the catheter.

The catheter move into a plastic pipe (6), if the slave-side detects friction,then the stepping motor (7) turns with the pulleys (5). Then the part 9 moves backward and puts pressure on the catheter. A resistive force sensor has been used to get the pressure on the pipe. The speed of the catheter getting by the sensor (3) decreases to reach the slave part speed. If the catheter of the slave crashes against a blood vessel, the motor (7) turns and put strong pressure on the catheter. Then the whole structure rolls due to the 2 cylinders (4) and a load-cell blocks it (8) : the surgeon force is recorded. The surgeon can pull the catheter (3) and the load-cell get this information and the catheter becomes free again.

B. Force Feedback

The coulomb dynamic friction law has been use (The friction force is independent of speed and only change with the pressure force) (2) and the fundamental dynamic theorem (3) on the catheter to find a relation between the forces.

$$\vec{f_r} = \vec{P_{feedback}}.tan(\phi) \tag{2}$$

Where f_r is the friction force, P_{device} the force given by the motor and $tan(\phi)$ the dynamic friction coefficient (determined by experiment). That's why the same catheter has been used for all the experiments: The materials have an important place which can change the settings controls. According to the Dynamic fundamental law applied to the catheter in the horizontal axis the equation (3) has been used an verified.

$$m.\ddot{u} = \vec{Hand} - \vec{P_{feedback}}.tan(\phi) \tag{3}$$

Where u is the catheter position of the catheter, $\vec{Hand}$ the force of the surgeon and $P_{feedback}$ the force puts on the catheter by the stepping motor.

The feedback force datas are recorded by a resistive force sensor. These one have a no-linear value as the equation (4) where Ω is the resistance in Ohm, a and b two constant.

$$Pressure = a.\Omega^{-b} \tag{4}$$

After that an electronic ad converter has been used to send the datas to the computer. With the equation (4) it's easy to find the relation between the Pressure on the catheter , where V_c the voltage, I the current:

$$Pressure = a.\frac{V_c}{I}^{-b} \tag{5}$$

IV. Experiments and results

A. Adjustment and test of the sensor

The first experiment has been proposed to adjust the sensor and find the two constants and find the relation between the sensor datas and the real motion of the catheter.

We used a translation platform driven by a stepping motor and a DSP controller. This translation platform move the catheter with high accuracy. Then the catheter has been moved to u mm by the platform and u points has been recorded by the sensor. The same experiment has been done with different lengths.Then the Figure 4 has been used to find the a constant of the equation 6.

$$U = a.X \quad (6)$$

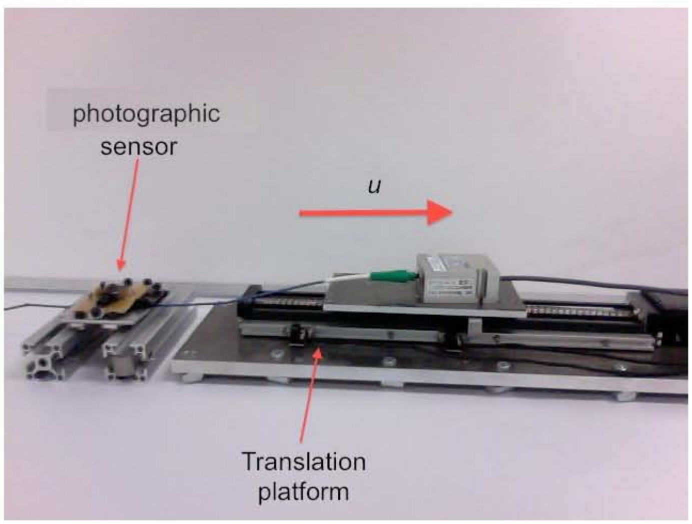

Fig. 3. Experimental system to adjust the sensor

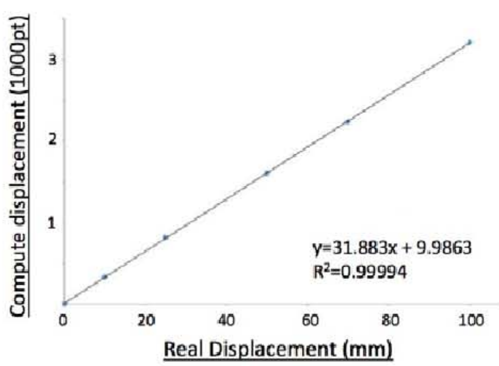

Fig. 4. Relation between computed displacement and translation platform

After this experiment the sensor has been tested with periodic motion with hand. The numeric derivate function has been used to find the speed (figure 5). The speed of the slave side and the speed of the catheter manipulating system can be compare in a close loop control for example.

This sensor has a 600 dpi resolution, it means a precision of 1/24 mm. This precision can be improve with an other sensor with high resolution like 6000 dpi (1/240 mm).

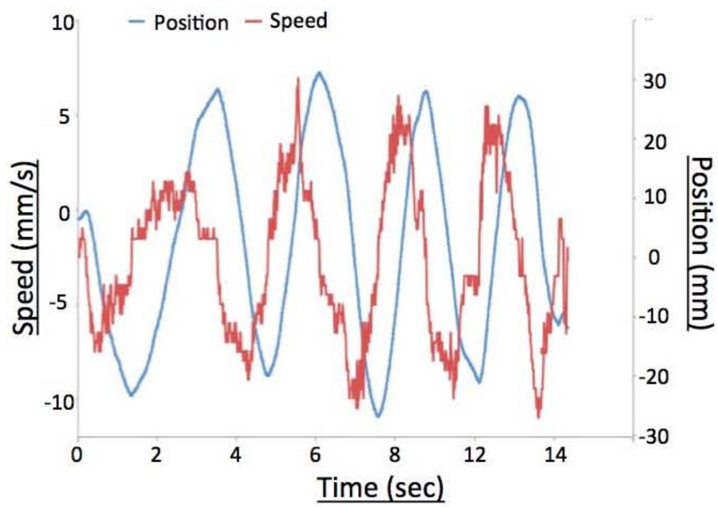

Fig. 5. Position and Speed experiment

B. Experiments on the haptic device

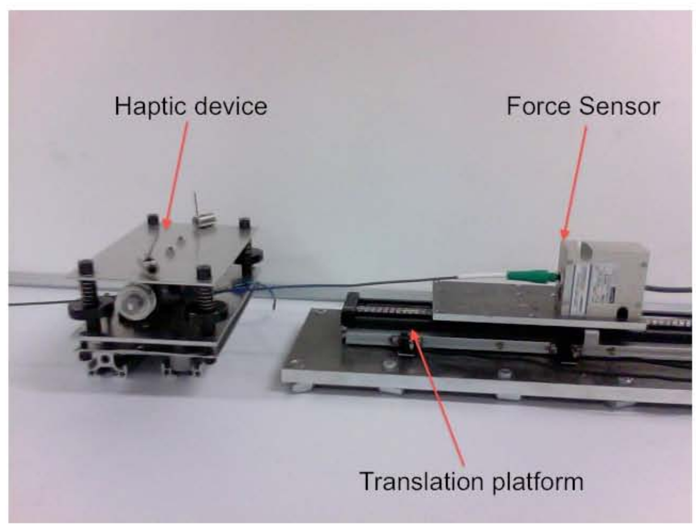

Fig. 6. Experiment system for haptic device testing

The first experiment has been done to find the relation between the drag force of the surgeon and the feedback force of the system. These datas are important to control the system. In fact this relation is useful to know witch pressure we can put to decrease the speed of the catheter.

As shown in the figure 6, the haptic device has been used and test with the translation platform and a load-cell to find the relation between the drag force of the surgeon hand and the Haptic force given by the system on the catheter. The platform drag the catheter with constant speed and the load-cell get the force datas. The same experiment has been done with different Haptic force. The experiment also has been done without haptic force to get the parasite force.

According to the figure 7 and the equation (3) the relation is linear. The coefficient of friction $tan(\phi)$ is 0.4191 and the number 0.034 is the parasite friction if the system don't push the catheter. The parasite friction is close to zero, the surgeon can move the catheter but he doesn't feel the system if this one is off.

A high accuracy stepping motor has been used with planetary gears. At last the system can push the catheter with the minimal step of 0.02 mm. The feeling of the surgeon can be changed with high accuracy.

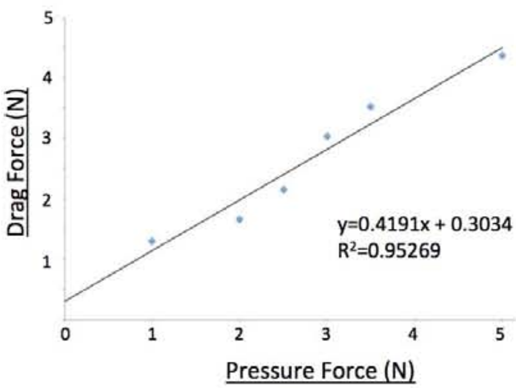

Fig. 7. Experimental results

$$F_{Drag} = 0.4191.F_{Haptic} + 0.034 \quad (7)$$

V. Conclusion

In this paper, a new robotic catheter manipulating system was proposed. A high precision mechanical system with motion sensor has been developed to assist surgeon for intra-vascular neurosurgery operation. A photographic sensor has been used to get the position and the speed of the catheter with high accuracy and precision. Due to this sensor the motion can be get without friction and the device is totally transparent for the surgeon.

In a second time a new haptic device has been developed. A high accuracy stepping motor has been used to put pressure on the catheter. Different pressures on the catheter change the feeling of the surgeon with a high accuracy.A system has been designed to get the force of the surgeon if the catheter crash against a wall. Finally the surgeon can manipulate the catheter with high accuracy and can have the feeling of a real operation.

In this paper, only the hardware part has been design. The next research will be focus on the control of the system and the communication between the slave and the master side. The system can be control with modern methods as Fuzzy control or Stochastic control .

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