Force Control in a Robotic System for Spinal Surgery

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Abstract: A robotic system for minimally invasive surgery of spinal surgery is developed. This system can diminish the surgical wound, avoid the radiation damage and reduce accidental injury in the spinal surgery. The architecture of the system and its control strategy are introduced. Appropriate control system is crucial to the robotic system, so position-force integrated control strategy is proposed. To get a better force control result, some necessary problems are analyzed.

1. Introduction

When doing a spinal surgery on patients who need pedicle screw placement or bone cement filling, it will drill a channel on the spine. But the appropriate drilling area is very narrow due to the special structure of the spine as shown in Fig.1. It is easy to accidentally injure spinal canal, nerves and blood vessels that close to the operating area.[1-4]

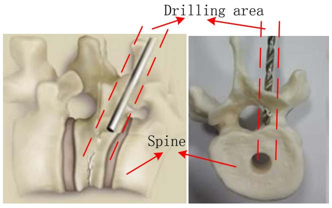

Fig. 1. the drilling area on the spine

To solve this problem, doctors use the X-ray to help keeping safety traditionally. But patients must be exposed in the X-rays, which also do harm to the patients and especially the doctors who exposed more frequently.

In order to reduce the radiation damage and improve the accuracy, security and stability of the high-demand surgery, we developed a robotic system for minimally invasive spinal surgery.

2. Robotic System for Spinal Surgery

We developed the system using master-slave teleoperation strategy. It consists of the master control console including a computer and an Omega7, the salve robot manipulator made up by a Universal Robot connecting a force sensor and a surgical drill at the end, and the camera. The system is shown in Fig.2.

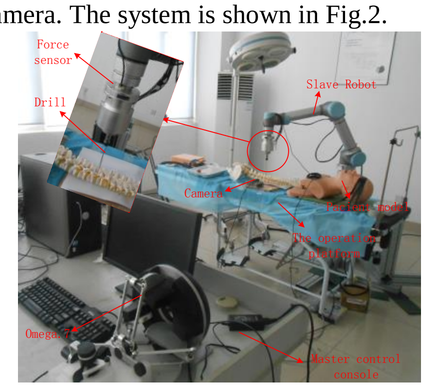

Fig. 2. the robotic system for spinal surgery

The doctor controls the master manipulator Omega7 to carry out the action command when operating. The action is determined by the doctor analyzing the information of the surgical site shown on the computer screen. The shown monitoring picture is obtained from the camera. The real operating action is completed by the slave robot which remains synchronized with the master.

3. Position-force Integrated Control System

Before the robotic system works, we must choose the right control system and develop a proper algorithm to ensure its good performance. The salve robot manipulator should reach the exact position instructed by the operator through the master device. Because of the high demand for accuracy, security and stability in the spinal surgery, the position control is not enough and the position-force integrated control is imperative. Because doctors should drill not only at an exact position on the spine but also into the exact depth using an exact drilling force, for the purpose of reducing tremble and avoiding unnecessary damage. So we decided to use a position-force integrated control system, which takes both position and force into consideration.[5,6] The control block diagram of the system is presented in Fig.3.

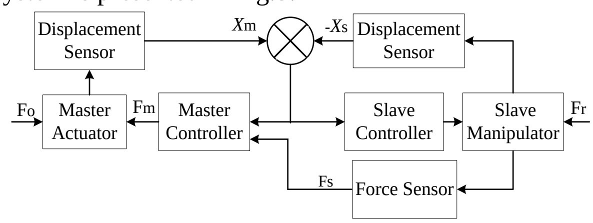

Fig. 3. Position-force integrated control system

In the diagram in Fig.3, *X*m refers to the position of the master, *X*s refers to the real position of the slave, Fs refers to the force obtained from the sensor, Fm refers to the force feedback to the master.

4. Preprocess for Force Control

We can infer from the preceding introduction of the robotic system that the force control in the system is especially important to fulfil a successful operation. But before achieving a successful force control, we must analyze and match the impedance of the system and must compensate the measurement error caused by the gravity of structure of the system.

When operating using the teleoperation system, it is much better to let operators feel as if they are performing the tasks directly. That means the system should be transparent to reach the high demand in the surgery. To achieve transparency, position and force obtained from the bilateral system should match simultaneously, which substantially means the impedance of the salve environment $Z_e(s)$ and the impedance felt by the operator $Z_v(s)$ should satisfy the transparency condition: $Z_v(s)=Z_e(s)$.[7,8] Combine with the block diagram of the position-force integrated control system, we can get the relation like: $z_v(s)=\frac{G_m(s)G_s(s)}{(1+G_s(s))}z_e(s)+\frac{G_m(s)}{s(1+G_s(s))}$.

To achieve good performance of force control, we should eliminate the measurement error caused by the structure of the robot to obtain the accurate force information from the force sensor. Because the force ${}^sF_s$ measured by the force sensor includes two parts: the real contact force ${}^sF$ and the gravity of the structure attached to the sensor ${}^sF_G$. The obtained redundant gravity ${}^sF_G$ may lead the obtained data ${}^sF_s$ to large fluctuation when the force sensor moving with the slave manipulator. So we need to remove ${}^sF_G$ to get a real value. Then the result will be: ${}^sF_r={}^sF_s-{}^sF_G$. All the force obtained should be under the system of coordinates of the force sensor.

5. Experiments and Conclusion

To see the effect of the force control, we designed the experiments on the spine model using our teleoperation robotic system. We handled the master device Omega7 and drilled four holes (A, B, C and D) on the spine through the monitoring image on the screen. As shown in Fig.4, the point W represents spinous process of the spine, which was touched when moving the drill from C to D because of the lack of visual depth information through the screen.

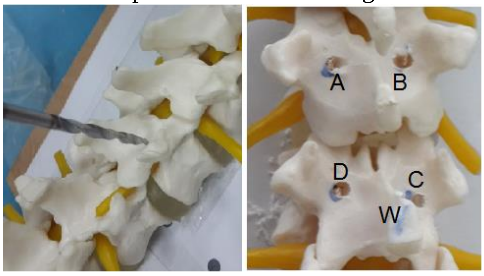

Fig. 4. the drilling tests on the spine model

During the experiments of drilling holes on the spine model, we got the force information from the control system as shown in Fig.5.

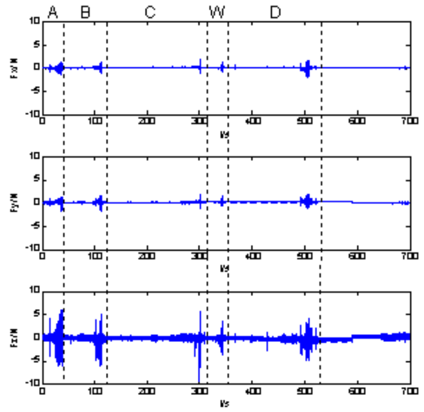

Fig. 5. Force data during drilling tests

The curves indicate that the force control system can be sensitive to the force change during the drilling process. The system can feel the unnecessary touch during its move. Thus the force control system can help the operator to feel the contact force and help operator to precisely control the force and the position when operating on the spine, which can greatly increase the probability of success for the spinal surgery and protect the other area of the body.

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