Control System of the Remote-controlled Surgical Robot for Guiding Puncture Needle

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Abstract. The mechanical arm for needle guidance consists of puncture link, RCM angle adjustment, and passive adjustment of mechanism position. The position of the passive mechanism was locked by manual adjustment, which requires certain locking moment, and the precision can reach 1 mm. In the process of angle adjustment of RCM, it was required that each joint should have an adjustment range of (+) 45 degrees and an adjustment accuracy of 0.5 degrees. Puncture requires high initial acceleration to penetrate human skin tissue. In this paper, the control system of the manipulator was studied.

Introduction

The minimally invasive surgical robot system was used to guide the needle to locate the needle. The remote control between them can adjust the angle by wireless handles or computer control platform, and display the relevant state[1,2], and control the final puncture needle in the same way, as shown in Figure 1.

![Figure 1. Overall control flow of manipulator.](image)

The minimally invasive surgery guiding robot was shown in Figure 2. The manipulation modes of the manipulator are as follows: height adjustment is to trigger the stepper motor by the button to drive the lead screw to achieve a specific height. The passive joint was locked by pressing the lock trigger button after manually changing the relevant position, showing the lock pressure and monitoring the pressure and joint angle in real-time. The angle of the RCM mechanism was adjusted to different rooms[3-7].
Degree of Freedom Configuration of Puncture Manipulator

The front-end RCM actuator consists of three degrees of freedom, two of which are used to adjust the rotation degrees of freedom of the needle tip posture, which need to be synchronously adjusted, and the third degree of freedom is used to realize the straight-line motion of the needle tip during the puncture process. Two of the rotational degrees of freedom need to be linked to achieving faster positioning of the desired attitude. At the same time, each passive joint needs locking function, and the distribution of each degree of freedom is shown in Figure 3.

The back-end positioning mechanism consists of three groups of passive rotating joints and one active up-shifting joint. To locate the puncture guide point more quickly, three joints are needed to move together. In figure 3, a small camera module was placed to monitor the anterior RCM joint, and a high-definition camera is placed far away to monitor the whole operation process.

Overview of Centralized Control System with Industrial Computer as the Core

Because of its powerful operation ability and good expansibility, computers were often used in industrial control. The controllers used in industrial field with good stability, reliability, and compatibility are collectively called industrial control computers. The main controller with the computer as the core control is the industrial computer with good expansibility.

The main hardware design work includes a master controller, joint controller, joint driver, a communication module, actuator, and feedback mechanism. The master controller of the upper computer is a personal PC host. The Maxon motor joint controller is driven directly by EPOS 2P
series controller of Maxon company. The other joint controllers were used as the lower computer, and Arduino is used as the control board. Control the movement of the driver by sending instructions. The main components of the computer control system are shown in Figure 4.

Figure 4. Composition of Computer Control System.

The control system is composed of EPOS2 driver and stepper motor driver, DC servo motor, stepper motor control board, pressure and position detection, control handle and keyboard, which support CAN bus protocol. The display function of each joint debugging computer software is shown in Figure 5.

Figure 5. Debugging computer software.

Workflow and Robot Entity for Puncture

The work of remote adjustment, RCM angle display, and remote needle insertion must be guaranteed after the completion of the early locking state. According to the time sequence, the position adjustment in the early stage and the posture adjustment in the later stage are carried out first. Safety-related functions include tip distance alarm, lock status monitoring, and alerting, as shown in Figure 6.

Figure 6. Workflow of control software.

The robotic system used to guide the needle was shown in Figure 7.
Summary

This paper describes a control system for a surgical robot used to guide needle puncture. Through the establishment of the control system, the whole system of the surgical robot and the upper computer software have been completed, which can better meet the requirements of minimally invasive surgery.

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