Two Layers CAN Bus Control Scheme for Minimally Invasive Surgical Robot

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1. Introduction

The motor control network of robotic arms is one of the core issues in the control system of surgical robot. As shown in Figure 1, our minimally invasive surgical robot uses multiple arms and the number of motors on each arm is up to 24 [1]. IPC used bus mode motor control network to control all the motors, this method uses fewer cables to achieve the control of multiple motor shafts without affecting the accurate control of motor or the corresponding real-time performance.

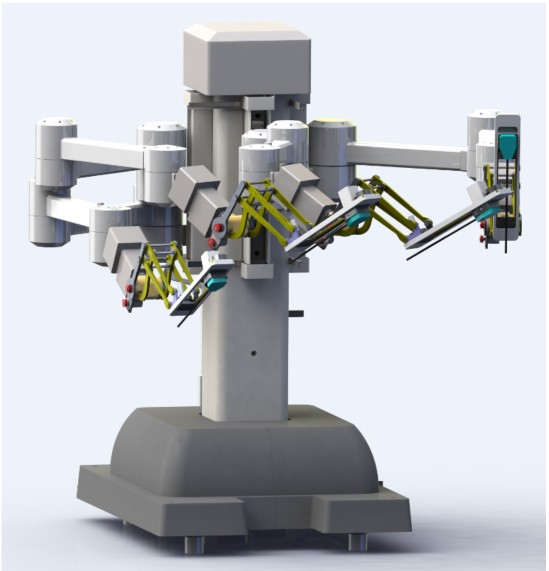

Fig. 1. Minimally invasive surgical robot system

The mainstream solution for bus mode motor control includes RS485, CAN and EtherCAT. The poor real-time performance of RS485 can't meet the requirement of our surgical robot. Although EtherCAT has a good real-time performance, the cost of using the master station and slave station of EtherCAT is very high.

The multi-motor control network based on CAN bus is suitable for the control system of surgical robot. CAN bus has many advantages including the low cost of board which supports the CAN protocol, better anti-interference performance, the ability for long-distance communication [2]. The improvement of communicating mechanism for the physical layer of CAN bus makes that it can get rid of the master-slave communication mode like RS485 and can realize free communication between CAN sites. This will help alleviate the burden of real-time operation of the IPC and can improve the real-time control of robotic arm.

2. Two Layers CAN Bus Topology

Our motor control network uses a tree-like CAN bus topology, it divides the 24 motor drives according to the robotic arm it belongs to and finally divides them into four CAN bus. Each arm has a CAN site as a relay site with two independent CAN ports. One of these two CAN ports is connected to CAN bus control signal line of the main controller, another port and all the additional motor drives are connected to the same motor control network.

Such CAN bus topology network is called two layers CAN bus motor control network. The first layer is used for the communication between the controller and the relay site of the controlled object, it regards the controlled object for example the robotic arm as a whole; the second layer is the control bus from the general node of the controlled object to the directly moving parts. Since the two layers CAN bus directly control the motion of motor, it helps the relay site achieve the synchronized control of the motors. The two layers motor control network topology of the minimally invasive surgical robot is shown in Figure 2.

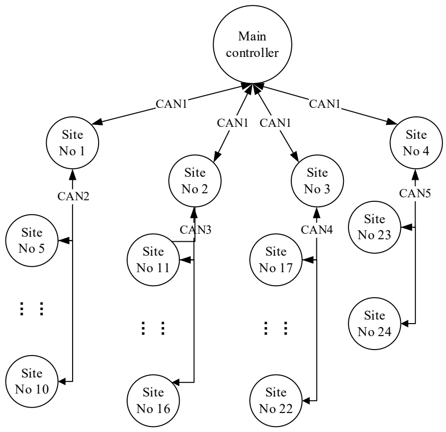

Fig. 2. Motor control bus topology diagram of surgical robot

The motor drives we use on the vehicle systems are MAXSON EPOS2 type drives which support CANopen protocol. There are 24 CANopen nodes in total. Each arm has a EPOS2 P motor drive with built-in PLC and some ordinary EPOS2 motor drives to control the motor operation. EPOS2 PLC has three CAN ports which are CAN-M, CAN-I and CAN-S. The CAN-M is the bus port of the high-level controller, it can be adjacent to the controller and form the first layer control bus connecting to CAN-M of the same EPOS2 P drive. CAN-I port control the built-in EPOS2 drives which control the motor connected. CAN-S port is the external CAN port, it can connect to the other EPOS2 drives and can also control the external motor drives by EPOS2 PLC programs.

3. Communication Protocol Design

The IPC and the EPOS2 P drives of four arms make up the first layer CAN bus. The bus has only five CAN nodes and each node follows the CANopen protocol [3]. In this communication bus, IPC only needs to communicate with the EPOS2 PLC inside the EPOS2 P driver of each arm. IPC send the control commands of motors from the CAN-M port to the PLC.

The second layer CAN bus consists of the connected CAN-I and CAN-S ports of each motor drive. The second layer CAN bus is the actual motor control bus and the communication data on this bus is motor position, velocity, acceleration control signal and the signal feedback from the motor drive including position, velocity and current.

Since the motor drive is directly controlled by EPOS2 PLC through CAN-I and CAN-S bus, EPOS2 PLC can decide on the control time of the motor. Since the motors of four arms are controlled by four EPOS2 PLC individually, it may lead to the out of step of the execution time for different arms due to the time delay of communication. This will go against the cooperative work of the robotic arm.

To achieve the synchronized control of motors on four arms, the control scheme has changed into this way: IPC sends the synchronized signal and after EPOS2 PLC on each arm receives the signal, the motor control commands will be executed. The synchronized command from IPC is achieved by one common data frame.

Thus, the communication process that IPC controls every motor on the four arms is as follows:

Firstly, IPC needs to send the control parameters of motors to EPOS2 PLC of each arm, then PLC will store the parameters in the register temporarily.

Secondly, After sending the required motor control data, IPC will immediately send a common data frame. When PLC of the four arms receives the common data frame, EPOS2 PLC will immediately send the control data of the motor drive on the second layer through CAN-I and CAN-S ports.

The flowchart that IPC sends the motor control data of four arms is shown in Figure 3. The longitudinal axis represents time, the left part represents the control command data for IPC and the right part represents the action of PLC on each arm.

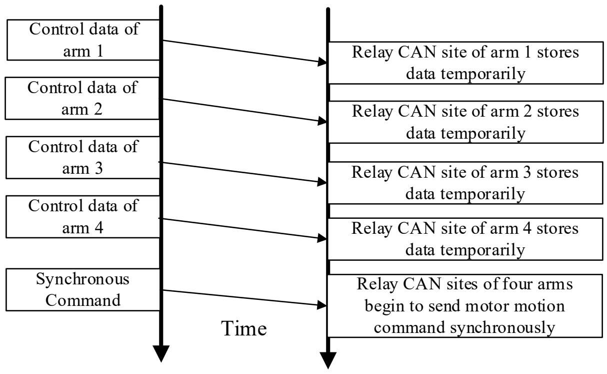

Fig. 3. Mechanical arm motor control data transmission process

4. Experiment and Conclusions

Based on the two layers CAN bus motor control structure, we design the synchronous experiment of motors in different arms. We send the same control data to both of the arms and test the execution time cycle and time delay of the same joints in different arms. We use the oscilloscope to contrast the time delay of the motor's feedback encoder in the same joint. The experiment data is recorded in Table 1. The experiment results show that this two layers CAN bus control scheme has a good real-time performance.

Table 1 Motor feedback data rate test.

Joint	Average time delay
1	0.7ms
2	0.8ms
3	0.8ms
4	0.9ms
6	0.6ms
7	0.7ms

We achieve the two layers CAN bus motor control structure using a programmable module. This control scheme has better real-time performance than the one layer motor control network. It has some other advantages including fewer nodes, less communication data and much better stability of the motor control network [4].

The EPOS2 PLC program needs to fulfil three tasks, the first task is that it needs to send the control data from the controller to the corresponding motor drive, the second task is that it needs to achieve the status monitoring and emergency handling of the seven motors, the third task is that it needs to take different control modes based on the controller setting. We will focus on the improvement of the programs according to these three tasks in the future.

Acknowledgments

This work is supported by the Technological Innovation Program of the Science and Technology Commission of Shanghai Municipality (Grant No.16441908500).

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