Development of a New Control System for the Robotic Single Port Surgery

Weibang Bai[1], Yang Cao[2], Pengfei Wang[1], Yo Kobayashi[3], Masakatsu G. Fujie[3], Qixin Cao[1]
1. Research Institute of Robotics, Shanghai JiaoTong University, Shanghai, China;
2. The Graduate School of Creative Science and Engineering, Waseda University, Tokyo, Japan;
3. The Faculty of Science and Engineering, Waseda University, Tokyo, Japan.
Correspondence to: W.Bai (bwb@sjtu.edu.cn); Q.Cao (qxcao@sjtu.edu.cn)

Abstract: Robotic assisted single port laparoscopic surgery is the new generation minimally invasion surgery. The research and development of robotic system for single port surgery became increasingly prevalent in recent years. A new kind of single port surgery robot which is based on double-screw-drive mechanism has been developed. In this paper, a new system combining the previous robot arm with a universal robot platform is developed and the new control system basing on the bus technology is set up. Besides, the master devices are also changed. The new system completes the remote center motion by active motion control, which is different from the conventional way. And the new control system make the whole system integrated and modularized, which benefits the practicability of the surgical robot system. The architecture, control system, working principle and main working procedures of the new master slave surgical robot system are introduced.

1. Introduction

Since the robotic laparoscopic single incision surgery turned up in clinical application in 2008 [1], the research and development of the new generation robotic system for single port surgery (SPS) have been becoming prevalent around the world. Few years ago, Y. Kobayashi et al. [2] have developed the new SPS robot whose mechanism is mainly based on double-screw-drive (DSD) and flexible shaft. Recently, we combined the robot arm with a Universal Robot as the platform base in the slave side, set up a new control system based on bus technology, and updated the master devices by using two Omega.7 (Force Dimension, Nyon, Switzerland) with 7 DOFs.

2. The Architecture of the New System

2.1 Combination with the UR Based Platform

As introduced in [2], the SPS robot arm is of 18 DOFs: two 7 DOFs serial-parallel robot hands, 1 DOF endoscope and 3 DOFs arm wrist. The picture in Fig.1 shows the main part of the real robot arm.

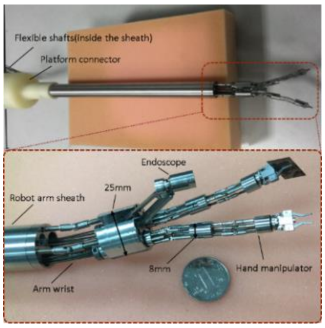

Fig.1. the SPS robot arm [2]

By combining the SPS robot arm with the 6 DOFs universal robot platform, as shown in Fig.2, we can make the SPS robot arm more dexterous in three ways. Firstly, the preoperative approach to the surgical field and getting into the single invasion become much more flexible and intelligent as we can directly drag or push the end of the universal robot platform to move, adjust and locate in a larger space. Secondly, the intraoperative maintaining and trimming of the pose of the instrument arm can be achieved accurately and the proper position of the operation remote center on the arm can be controllable at real time. Thirdly, once the end arm reached to the right pose by the active control, the platform will be switched to be locked and keep the pose; so it is very convenient to change the state of the base platform without fluctuation of rigidity and accuracy.

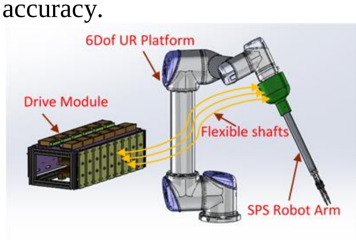

Fig.2. the structure of the combined slave robot system

2.2 New master device and new architecture

In the previous robotic system, the master devices were developed by combining PHANTOM Omni (SensAble Technologies, Inc., MA, US) [2] Now we use two versatile haptic devices called Omega.7, whose end-effector covers the natural range of motion of human hands and is of 7 DOFs already. It can provide more accurate and more integrated information of inputs by the operator. The hardware architecture of the new master-slave SPS robotic system can be seen in Fig.3.

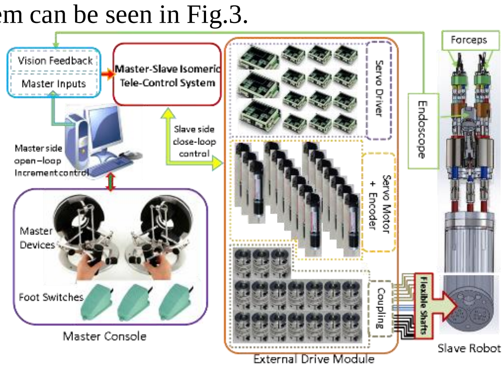

Fig.3. the hardware architecture of the new system

3. The remote center motion of the new system

Surgical robot system need remote center motion to keep safe and avoid damage to the incision. Most surgical robot use the remote center mechanism (RCM) to realize that, and the previous system in [2, 3] also has a 4 DOFs positioning manipulator using parallel mechanism.

In this new system, the remote center Rc (in Fig.4) coincides with the incision and should be almost a fixed point in the base coordinate during the operation. But the distance parameter d_6 may change as the end effector moves or the incision shakes in the real case. Besides, the relative position of remote center and the pose of the end instrument may need to be adjusted during the operation. All these special requirements can be reached by the UR platform basing on motion control combined with additional conditions. Firstly, the kinematics equation of the platform can be obtained using the famous method of Denavit-Hartenberg (DH) transformations according to the joints' coordinate system setup in Fig.4, and we have:

$$ {}^{0}T_C = {}^{0}T_1\,{}^{1}T_2\,{}^{2}T_3\,{}^{3}T_4\,{}^{4}T_5\,{}^{5}T_6\,{}^{6}T_C = f(q) \quad (1)$$

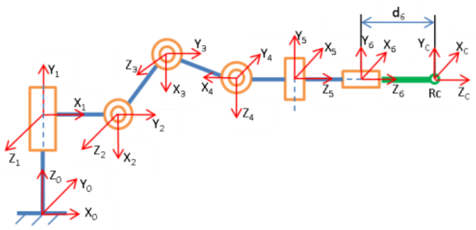

Fig.4. the structure and coordinates of the UR platform

In(1), ${}^{i-1}T_i\ (i = 1, 2, \cdots 6)$ are the transformation matrices, the target pose of Rc is restricted by the real requirments, and we can get ${}^{0}T_C = T_{known}$. The distance d_6 may have a small variation Δd while keeping the remote center Rc coinciding with the incision, and $\Delta d \in S(d)$. Then:

$$\begin{cases} f(q, \Delta d) = T_{known} \\ s.t.\ \ \Delta d \in S(d) \end{cases} \quad (2)$$

As suggested in the configuration diagram in Fig.4, few of the axes of the 6R robot are parallel and few are intersecting. So the equation (2) can get closed-form solutions. Following the optimal solution obtained, we can control the platform robot and realize the remote center motion in an active way rather than the conventional passive method which is depend on the special mechinism. Once the right pose is ready, we can lock the state of the platform and then start the teleoperation surgery, which means we can keep it safe in a passive way.

4. The new control system and the working principle of the new system

The previous control system is based on enhanced industrial personal computer which connects a few data acquisition cards to obtain data. While controller area network (CAN) bus technology can provide high reliability and good real-time performance with low cost. So we setup the new control system based on the CAN bus to get efficient and reliable communication between upper computer and actuators, sensors, controllers at each node in real time. By this way, the control system can be more integreted and compact, and the drive sysytem and the robot arm system can be modularized, which benefit the practicability of the robotic system a lot.The topology of the new control system is shown in Fig.5.

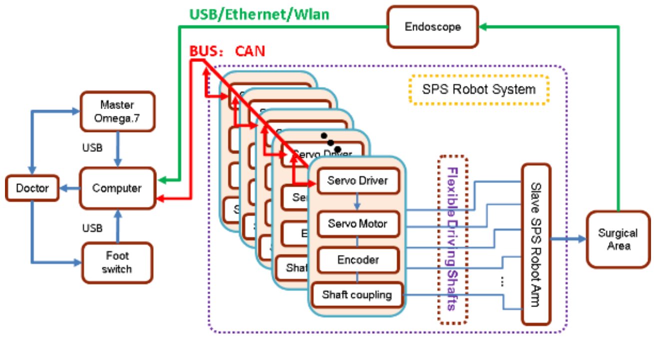

Fig.5. the new control system based on CAN bus

The schematic diagram in Fig.6 indicates the working principle of the new control system, which is a typical isomeric master-slave robotic system. So the mapping strategy between the master space and the slave space is needed. Depending on the visual feedback information of the surgical area in real time, the doctor will judge and give proper commands to the master device Omega.7, and pose increments which are the control inputs will be generated.

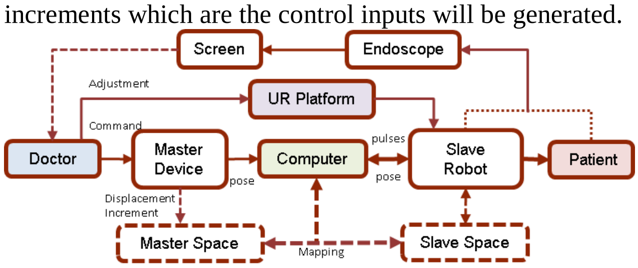

Fig.6. the working principle diagram

5. Conclusion

Based on the previous achievements, we set up a new system combining the SPS robot arm with the 6 DOFs UR platform to complete single port laparoscopic surgery. We choose the new haptic device Omega.7 as the new master input devices, and control the entire new system using CAN bus technology. Furthermore, we realized the remote center motion intelligently and safely by active motion control rather than the conventional way that depends on the remote center mechanism. The new control system make the whole system integrated and modularized which make it more convenient to apply to clinical application. The combination with controllable platform, the updated master devices, the application of the communication bus, and the new operation procedures make the new system more intelligent and higher maneuverability.

Acknowledgement

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