A Remote Center of Motion (RCM) Mechanism for Minimally Invasive Surgery (MIS)

Pengfei Wang[1], Yang Cao[2], Weibang Bai[1], Hongbin Tan[1], Yo Kobayashi[3], Masakatsu G. Fujie[3], Qixin Cao[1]
1. State Key Laboratory of Mechanical System and Vibration & 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: P.F. Wang (wpf790714@163.com; wpf790714@sjtu.edu.cn)
Q.X. Cao (qxcao@sjtu.edu.cn) ,

Abstract: Remote center of motion (RCM) mechanism is a mechanism which is bound by kinematics and could rotate about one point not belonging to it. A specific parallelogram RCM is presented in this paper for a surgical robot designed to achieve robot-assisted minimally invasive surgery (MIS) for laparoscopic diseases treatment. The parallelogram RCM adopts harmonic reducer and servo motor driver in order to avoid the instability of pulley drive. Compare with other RCM mechanism, the transmission mechanism presented in this paper provides large output torque and high accuracy. In this paper, the transmission mechanism and structural strength is considered in detail. Eventually, a suture simulation test is given and results demonstrate that the repetitive positioning accuracy of the specific RCM mechanism meet the demand of practical surgery operation.

1. Introduction

Minimally invasive surgery (MIS) have been widely used in laparoscopic surgery. The MIS have great benefits for patient due to the less abdominal injuries compared to conventional surgery. The remote center of motion (RCM) mechanism is designed to realize specific rotate about a point not physically belonging to it. Therefore, the RCM mechanism is the key factors how to decrease the surgery injuries.

Researchers studied MIS and RCM mechanism for surgery operation in the past many years. They focus on various mechanical configurations for achieve mechanism innovation. So far, the most MIS is implemented through heterogeneous master-slave teleoperation mode [1-3], as shown in Fig. 1. However, the transmission mechanism among many RCM is not be considered in detail. Hence, we should develop the RCM mechanism with the same configuration and difficult transmission design in this paper.

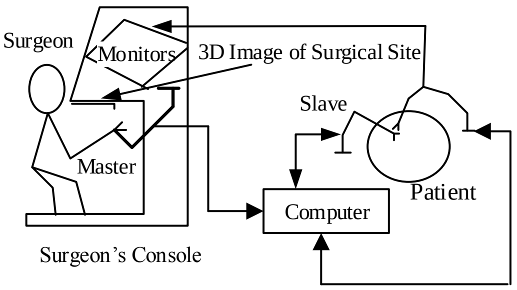


Fig. 1. The master-slave teleoperation mode.

2. Methods

2.1 Design requirements

For general operation demand, the RCM mechanism should have high structural stiffness and low backlash.

Therefore, the surgical tool should be manipulated with four DOF. Among of them, three rotations about the incision point (Pitch, Yaw, and Roll) and one insertion along the tool [4]. Table 1 shows the other functional requirements of master robot for MIS. These data are based on the survey reports on MIS in the abdominal cavity [5].

Table 1 Functional requirements for a master robot to be used in MIS of the abdominal cavity.

Parameter	Direction	Value
Workspace(23,24)	Pitch	90º
	Yaw	±60º
	Roll	150º
	Insertion	200 mm
Maximum velocity	Lateral	0.2 m/s
	Insertion	0.2 m/s
	Roll	30 rpm

2.2 Transmission mechanism

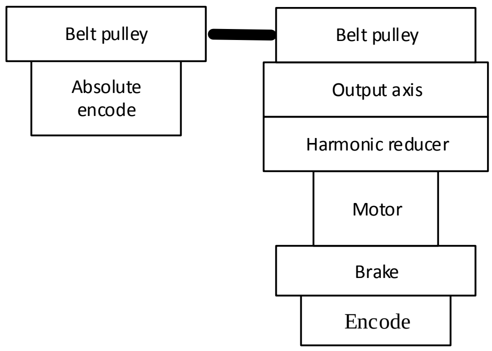


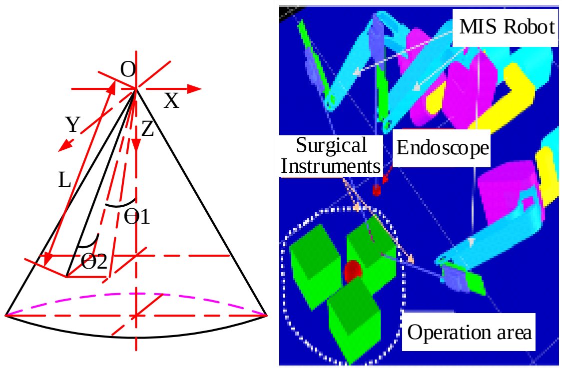
Fig. 2. Transmission mechanism for rotational joint.

Considering the trade-off of the maximum between torque and velocity, the actuators of each rotational joint should select using the maximum load of 10N. According to relative kinematics and dynamics analysis, transmission mechanism should include high-ratio reducer. Figure 2 shows the transmission mechanism for rotational joint. The high precision harmonic reducer and absolute encode ensure the realistic accuracy demands.

3. Result and Discussion

3.1 Position accuracy

As shown in Fig.3 (a), the repetitive position accuracy should be given as Eq. (1).



(a) (b)

Fig. 3. Parallelogram RCM mechanism is installed on prototype of the surgical robot.

$$\begin{cases} dx = dl \bullet cos\theta_1 sin\theta_2 + d\theta_1 \bullet lcos\theta_1 cos\theta_2 \\ \qquad - d\theta_2 \bullet lsin\theta_1 sin\theta_2 \\ dy = dl \bullet sin\theta_2 + d\theta_2 \bullet lcos\theta_2 \\ dz = dl \bullet cos\theta_1 cos\theta_2 - d\theta_1 \bullet lcos\theta_1 sin\theta \\ \qquad - d\theta_2 \bullet lcos\theta_1 sin\theta_2 \end{cases} \quad (1)$$

Here, dx , dy , dz represent the error in the direction of X, Yand Z, respectively. dl is the error of l . And θ_1 and θ_2 is the projecting angle.

Figure 3 (b) shows a prototype of the surgical robot developed which is installed on parallelogram RCM mechanism. Assuming the angle resolution is 0.25°, the position accuracy of master robot is no more than 1 mm from the Eq. (1). The accracy satisfies the surgical operation.

3.2 Suture experiment

A preliminary suture test is carried out to verify the operational performance for RCM mechanism.

Firstly, the work space of master robot was measure, which demonstrate its correctness. The results of the suture experiment on the prototype of the surgical robot shows that the mechanism is able to work in the entire work space mentioned in Tab. 1.

Sencondly, the flexibility of the RCM mechanism is tested through skilled suture operation, as shown in Fig. 4.

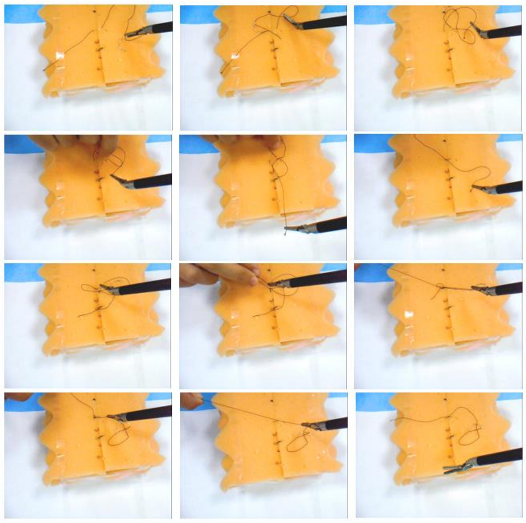


Fig. 4. Suture test using a surgical robot developed.

4. Conclusion

This paper presents a special RCM mechanism, which has a particular transmission mechanism and meet the realistic suture conditions. Experiments demonstrate that the parallelogram mechanism has adequate structural strength and high accuracy. Further experimental tests are in progress to evaluate the working performance.

Acknowledgement

This research was supported by the National Science Foundation of China (NSFC), No. 81371650.

References

[1] R. H. Taylor, J. Funda and D Larose et al., “A telerobotic system for augmentation of endoscopic surgery”, IEEE Medicine & Biology Conf., Paris, USA, pp.1054–1056, 1992.

[2] R. H. Taylor, J. Funda and B. Eldridge et al., “A telerobotic assistant for laporoscopic surgery”, Engineering in Medicine and Biology Magazine, 14(3), pp. 279-288, 1995.

[3] R. H. Taylor,P. Jensen and L. Whitcomb et al., “A steady-hand robotic system for microsurgical augumentation”, the International Journal of Robotics Reasearch, 18(12), PP. 1201-1210,1999.

[4] C. H. Kuo, J. S. Dai and P. Dasgupta et al., “Kinematic design considerations for minimally invasive surgical robots: an overview”, Int J Med Robotics Comput Assist Surg, 8, pp. 127-145, 2006.

[5] A. L. Trejos, R. V. Pael and M. D. Naish, “Force sensing and its appliations in minimally invasive surgery and therapy: a survey”, Proc. IME, Part C: J Mech Eng Sci 224, pp. 1435-1454, 2010.

[6] T. Geepel, F. Haertl and A. Shneider et al., “Automation of a suturing device for minimally invasive surgery”, Surg Endosc Intervent Technique, 25, pp. 2100-2104, 2011.