DESIGN OF A NEW LAPAROSCOPIC-HOLDER ASSISTING ROBOT

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ABSTRACT

The minimally invasive surgery (MIS) is new technology of surgery. There are many advantages to patient to use this technology. The laparoscopic surgery, a type of MIS, is performed with several laparoscopic tools and with a laparoscope. In this paper, design of a new laparoscopic-holder assisting robot is developed to help the primary surgeon. The system is a 5 DOF robotic system to hold and control laparoscope. The design is improved from well-known laparoscopic robots, the KaLAR robot and the MC^{2}E robot, to reduce some disadvantages from our analysis. The robot base is enhanced from the lower part of the MC^{2}E robot and the holder is adjusted from the laparoscope-holder of the KaLAR robot while other parts are developed by our own. In conclusion, the study presented in this paper is a consequence sub-project of the development of robot-assisted laparoscopic surgical system project.

1. INTRODUCTION

The development in medical treatment is heading toward the minimization or elimination of incision. This minimization of incision is minimally invasive surgery (MIS) [1]. There are several advantages to the patient who operate on the MIS by reduced blood loss which reduces the risk of needing a blood transfusion, smaller incision which reduces pain and shortens recovery time, less pain leading to less pain medication needed, shortening the recovery time, and reduced exposure of internal organs to possible external contaminants thereby reduced risk of acquiring infections.

Laparoscopic surgery, a type of MIS, is performed with several laparoscopic tools and with a laparoscope which is a telescopic rod lens system that is usually connected to a CCD camera. Also attached is a fiber optic cable system connected to a light source which to illuminate the operative field. These tools inserted through a 5 mm or 10 mm three to five openings called ports in the abdomen. The surgical site is viewed through a laparoscope equipped with a CCD camera.

In operating room for laparoscopy has much number of surgeons depended on surgical types and surgeon's techniques, shown as Figure 1 [2]. The position in operation room for laparoscopy the camera operator stands beside the primary surgeon and first assistant is on the opposite side the primary surgeon. The primary surgeon mainly operates and the first assistant surgeon supports the primary surgeon.

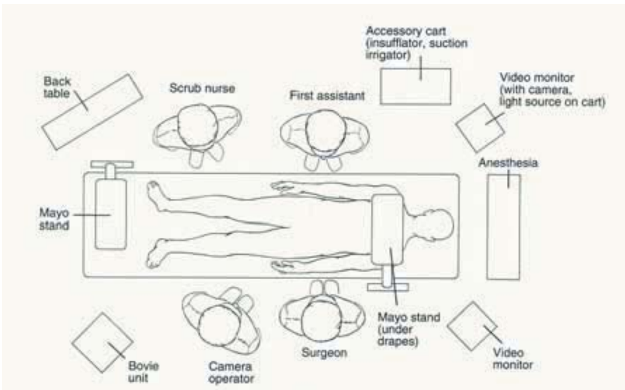

Figure 1. Operation room configuration (Courtesy [2]).

From Figure 1, the operating room has many surgeons, so the work space is limited, shown in Figure 2 [3]. This figure shows the complexity of working of a real operation room. Sometimes the camera operator needs to manipulate the laparoscope through a very small space such as the primary surgeon's underarm and changed the position of the laparoscope by the instruction of the primary surgeon.

The camera operator is inexperienced who has projected the image of wrong view. The problem of human factors such as tremor and fatigue are critical factors that influence the outcome of the surgery. This paper would to eliminate these factors and improve the outcome by using robotic technology.

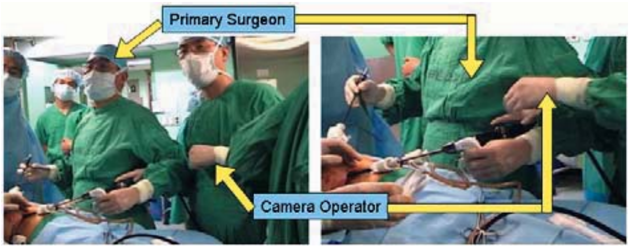

Figure 2. The complexity of real operation room between the primary surgeon and camera operator.

2. RELATED WORK

The laparoscope-holder assistant robot had been developed two types consists of the commercial and uncommercial. The part of commercial laparoscope-holder system has many systems such as the AESOP (the automated endoscope system for optimal positioning) system (Computer Motion Inc, Goleta, CA [4]), EndoAssist (Armstrong Healthcare, High Wycombe, Bucks, UK [5]), and LapMan (MEDSYS, Gembloux, Belgium [6]) and the part of uncommercial laparoscope-holder system has many systems such as LER, Light Endoscope Robot, developed by TIMC-GMCAO Laboratory [7], KaLAR, KAIST Laparoscopic Assistant Robot, developed by Korea Advanced Institute of Science and Technology [8], and MC^2E, compact manipulator for endoscopic surgery, developed by Laboratorie de Robotique de Paris [9]. This paper would be developed the new laparoscope-holder robot by used the advantages of the uncommercial laparoscope-holder systems.

The LER system is light endoscope-holder robots. This system is a lower cost robot. This system consists of a compact camera-holder robot, shown as Figure 3, resting directly on patient's abdomen, and an electronic box containing the electricity supply and robot controller. From figure 3, this system has 3 DOFs consist of one motor is used to control the endoscope's insertion depth (extension motor), the second enable core needle to rotate on an axis (rotation motor), and the third enables endoscope pan-tilt (inclination motor).

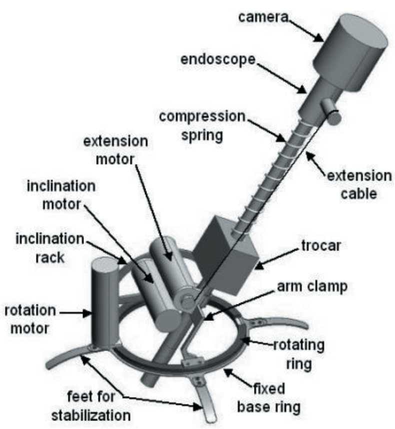

Figure 3. LER (Light Endoscope Robot).

The KaLAR system is an assistant endoscope-holder robot. KaLAR has 3-DOF that includes up/down, left/right and forward/backward movement, shown in Figure 4. From figure 4, this system has the end tip of the KaLAR has a CCD camera, optical fibers and the bending section. The control of the KaLAR consists of 2-DOF motions for up/down and right/left motions controlled by wire-driven mechanism, and 1DOF zooming mechanism makes forward/backward movement from the linear-stage controlled by motors. These motions controlled by software computer.

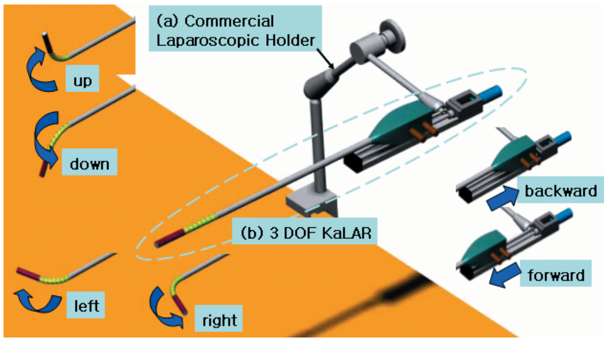

Figure 4. Simulation of KaLAR in conceptual design.

The MC^2E system moves not only the instrument but also the trocar in which the instrument is inserted. This robot consists of two parts, as shown in Figure5. This system consists of two parts. The first part, the lower part is a compact spherical 2DOF mechanism ($\Theta1$ and $\Theta2$) which joint axes coincide with the trocar center. This provides an invariant center at the fulcrum point. The base of this lower subsystem is easily installed on the patient's skin and clipped to the trocar. The second part, the upper part of the robot is mounted on the trocar. It provides the two DOF for the rotation about the instrument axis (Θ_3) and translation along the instrument axis (d_4).

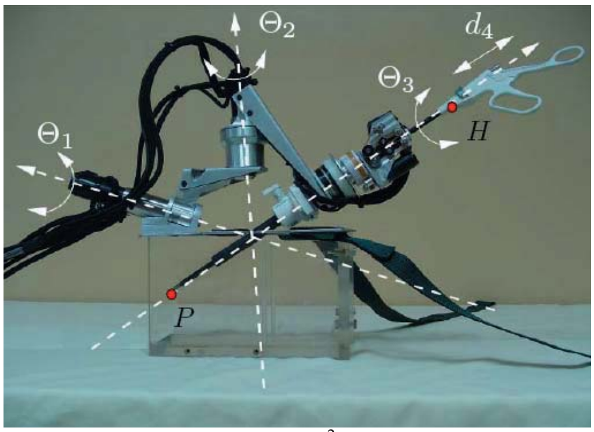

Figure 5. MC^2E robot.

From these systems, this paper combined advantages of all structure and designed new assistant laparoscope-holder robot. This robot will represent in chapter 3.

3. CONCEPTUAL DESIGN ROBOT

This entire system consists of three parts: a passive base, a bending laparoscope, and an external manipulator.

3.1. Passive base

This robot system can use in the surgical environments which has the work space to minimize. In design of this robot system will consider a lengthy set-up time. Therefore, the commercial medical passive holders that can be climbed easily on the operating table were used. The passive base can be fixed to the operating table with a clamp which setup the system at the proper position and attached the additional link to the passive holder [10]. The additional link is used to determine the remote center of motion that is incision point during the installation process. This part will show in Figure6 [11].

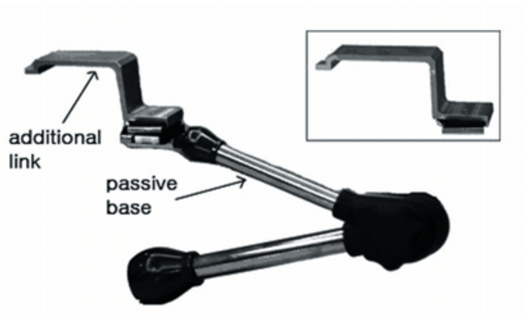

Figure 6. Additional link with a passive base.

3.2. Bending laparoscope

The bending laparoscope was retained from the original KaLAR system. This part is composed of 2DOF of bending motion inside the patient's abdomen and 1DOF of in and out motion outside the patient's abdomen. The 2DOF of bending motion driven by a wire mechanism determines the internal angle of the laparoscope. The 1DOF of zooming motion use a linear guide with a ball screw. This part will show in Figure7.

Figure 7. KaLAR with passive system.

3.3. External mnipulator

The original KaLAR system has a limited view of workspace. This system would be difficult to apply to other laparoscopic surgeries. This paper will be developed the external manipulator was developed to extend the workspace of the original KaLAR system. This external manipulator will be combined motion of the original KaLAR system and the external manipulator will be used the lower part of the MC^2E, Shown in Figure5. The advantages of the new system can provide a wide view of the workspace in the abdominal cavity and allowing this system applied to the other laparoscopic surgeries. The external manipulator has 2DOF of motion which created the compact spherical motion for move the laparoscope.

Moreover this system doesn't have a large rigidity problem and it has very simple structure, thus the surgeon can predict the movements of this system easily and reduced the interference in the system.

3.4. Prototype of the system

The prototype of this laparoscope-holder assistant robot is structure shown in Figure8. This robot designed by combine both robots, the KaLAR robot and the MC^2E robot. The base part of this robot designed from the lower part of the MC^2E robot, for this part can easily adjust the position of the laparoscope-holder and can easily control because this part has 2DOF mechanism. This part use control the invariant center at the fulcrum point. The laparoscope-holder part of this robot designed from the laparoscope-holder of the KaLAR robot, for this part can easily predict the movement of laparoscope and can easily calculate the position of the laparoscope tip. This part has 3DOF mechanism composed of 2DOF for bending motion in the patient's abdomen and 1DOF for in and out motions of the laparoscope outside the patient's abdomen.

From the design of this robot have many advantages: First, this robot can easily develop because this robot used three motors and simple linkages. Second, this robot can easily calculate the laparoscope tip because has 5DOF of motion consists of 2DOF of control the center of fulcrum point and 3DOF of control the motion of the laparoscope. Third, this robot can easily control the laparoscope motion because this robot can control by voice command of the surgeon. Finally, this robot can easily setup the position center to use, used small workspace in the surgery room, and not interference the workspace of the primary surgeon because this robot is very small robot.

From these advantages of the new design laparoscope-holder assistant robot can use in the laparoscopic surgery. The primary surgeon can control the new robot by surgeon's instruction. The new design can decrease time in the surgery. Thus, the new design laparoscope-holder assistant robot can help holder laparoscope in the laparoscopic surgery.

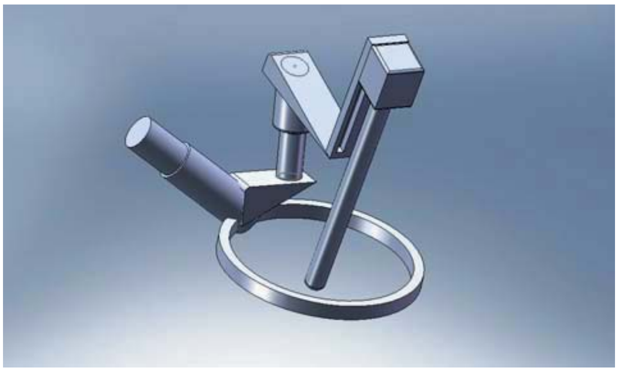

Figure 8. Structure of the new laparoscope-holder robot.

4. CONCLUSION

In this paper studied many robots such as commercial laparoscope-holder system (for examples: AESOP, EndoAssist, LapMan) and uncommercial laparoscope-holder system (for example: LER, KaLAR, and MC^2E). In this paper considered the many advantages from the many robots for design a new laparoscope-holder robot. The design of this robot combined two structure robots, KaLAR robot and MC^2E robot. This robot separated as two parts. The first part, the base part of this robot designed from the lower part of the MC^2E robot. This part has 2DOF mechanism for control the invariant center at the fulcrum point. The second part, the laparoscope-holder part of this robot designed from the laparoscope-holder of the KaLAR robot. This part has 3DOF mechanism composed of 2DOF for bending motion in the patient's abdomen and 1DOF for in and out motions of the laparoscope outside the patient's abdomen.

From the design of this robot have many advantages: First, this robot can easily develop. Second, this robot can easily calculate the laparoscope tip. Third, this robot can easily control the laparoscope motion. Finally, this robot is very small robot. These advantages of the new design laparoscope-holder assistant robot can use in the laparoscopic surgery because the primary surgeon can control the new robot by surgeon's instruction, and the new design can decrease time in the surgery. Thus, the new design laparoscope-holder assistant robot can help holder laparoscope in the laparoscopic surgery.

ACKNOWLEDGEMENT

This project is mainly funded from a Thai Government Budget through Ministry of Science and Technology, year 2008-2011, and the first author is supported by TGIST of NSTDA.

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