Master-Slave Robotic System for Therapeutic Gastrointestinal Endoscopic Procedures

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INTRODUCTION

Flexible endoscopy is used to inspect and treat disorders of the gastrointestinal (GI) tract without the need for creating an artificial opening on the patient's body (Phee, Ng, Chen, Seow, & Davies, 1997). The endoscope is introduced via the mouth or anus into the upper or lower GI tracts respectively. A miniature camera at the distal end captures images of the GI wall that help the clinician in diagnosis of the GI diseases. Simple surgical procedures (like polypectomy and biopsy) can be performed by introducing a flexible tool via a working channel to reach the site of interest at the distal end. The types of procedures that can be performed in this manner are limited by the lack of maneuverability of the tool. More technically demanding surgical procedures like hemostasis for arterial bleeding, suturing to mend a perforation, and fundoplication for gastrooesophageal reflux cannot be effectively achieved with flexible endoscopy. These procedures are often presently being performed under opened or laparoscopic surgeries.

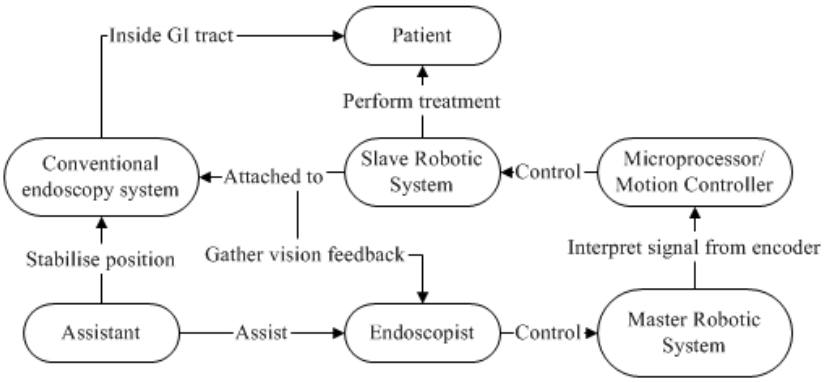
With the invention of medical robots like the Da Vinci (Intuitive Surgical Incorporation) surgical systems, clinicians are now able to maneuver surgical tools accurately and easily within the human body (Carrozza, Dario, & Phee, 2003). Operating from a master console, the clinician is able to control the movements of laparoscopic surgical tools real time. These tools (also known as the slaves) are designed with sufficient degrees of freedom to move according to the natural hand and wrist motion allowing the clinician to perform intricate procedures with minimal technical difficulties.

Thus far, master-slave surgical robotic systems like Zeus and Da Vinci are either completely rigid or do not have a significant length of flexible body (Low & Phee, 2004). The slave manipulators enter the human body by means of incisions on the body. In this article, we propose a robotic system with flexible slave manipulators that could be attached directly to flexible endoscopes. Similar to a conventional flexible endoscopic procedure (e.g., gastroscopy), the "robotic endoscope" bundle could negotiate the curves and bends in the GI to reach the desired position within the gut. This system empowers the surgeons to perform more difficult surgeries that are otherwise impossible with the conventional endoscopic tool.

OVERALL ROBOTIC SYSTEM

Figure 1 shows the proposed system layout whereby the endoscopist work on the master console while gathering visual feedback from the endoscope. A

Figure 1. Proposed system layout for the overall robotic system



computer console will interpret the readings from the master console that will in turn give instruction to the slave robotic system to perform the treatment to the patient. This system allows complicated treatment to be performed with the added benefit of easy and intuitive control for the endoscopist.

THE SLAVE MANIPULATOR

The 3D model of the intended slave manipulator can be seen in Figure 2. In order for the surgeon to perform the necessary dexterous actions, the slave manipulators should possess a high number of Degrees of Freedom (DOF). The emphasis of the project is to make the slave manipulator to be as intuitive to control as possible. As such, the DOF and joints of the slave manipulator are modeled after a simplified human arm as shown in Figure 3. Altogether there are five DOF for positioning of the slave and an extra DOF for manipulating the end effector and the axis or rotation. Two slave manipulators are used instead of one since it can perform actions such as pulling and cutting of polyps or suturing bleeding sites. Furthermore two slave manipulators are more intuitive to use since they resemble the two human arms.

In order for the slave manipulator to be able to go through human GI tract, the slave manipulator has to be small yet flexible. Due to this unique requirement, tendon-sheath actuation is used. The prime movers are located outside the human body and it transmits power to the mechanism by pulling and releasing tendons in a sheath accordingly.

Figure 2. 3D model of slave manipulators attached with the endoscope