Compact Modular System Design for Teleoperated Laparoendoscopic Single Site Surgery

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Abstract—We report a preliminary design of a compact robotic system for teleoperated laparoscopic-endoscopic single-site (LESS) surgery. The system will be sterilizable by autoclave, immersible for cleaning, and portable. This system was developed from the previous University of Hawaii compact laparoscopic robot system and will be built upon the base of a ViKY XL endoscope robot from EndoControl SA.

The system is composed of two instrument manipulators and one endoscope manipulator attached to a common rotating base ring and support frame, allowing the articulated instruments and endoscope to be inserted into the body through a single common incision and trocar. The support frame bars on either side of the base ring have gear teeth so that the insertion depth of each instrument or endoscope can be actuated by rack-and-pinion mechanisms. The endoscope is directly attached to the support frame by its rack-and-pinion drive, while each instrument is attached to its rack-and-pinion by articulated links and a universal joint, to allow independent motion while inserted through the common incision.

I. INTRODUCTION

A. Laparo-Endoscopic Single-Site Surgery

Single-port access (SPA) surgery [1] or laparo-endoscopic single-site surgery (LESS), is a recently developed technique to perform laparoscopic surgery by passing multiple instruments through a single incision, typically in the navel. No visible scarring is generated and instruments similar to standard laparoscopy may be used. Access is more direct than natural orifice surgery (NOTES) and the lack of triangulation from the single incision can be mostly overcome by using angled or articulated instruments.

Single-port laparoscopic surgery has the well-known advantage of minimal and hidden scarring compared to standard minimally-invasive laparoscopic surgery, yet avoids the complexity and limitations on accuracy, stiffness, and dexterity of NOTES. Single-port surgery could also benefit from the improved ergonomics, accuracy and dexterity provided by teleoperated robotic surgery systems, however it is difficult to use existing surgical robot systems in a single port configuration due to interference between the robotic arms which manipulate the surgical instruments and endoscope. More compact mechanisms to position and manipulate the surgical instruments would allow at least three instruments to be teleoperated while inserted in a single common port.

Our simple, compact, modular surgical system provides advantages in safety, portability, cost, and ease of use in setup and operation compared to currently available systems. Our design is a modification of our previous prototype teleoperated minimally invasive surgery system, combined with the ViKY XL system from EndoControl SA. A further aim of our described system is to enable intraoperative transitions between open and minimally invasive, manual and teleoperated, single-site and multiple incision operation.

The ViKY XL system shown in Fig. 1 has been shown to be well suited for use in manual LESS surgery [2], [3]. The previous University of Hawaii surgical robot system is shown in Fig. 2 and described in detail in [4].

B. Related Work

A bimanual system for robotic single-port laparoscopic surgery has been developed [5] with a single inserted shaft...
which separates inside the body. LESS surgery has also been performed using the daVinci Si system from Intuitive Surgical using modified instruments [6], however it is reported that this system is not ideal due to collisions between the instrument manipulators [7].

II. DESIGN

The basic design schematic of our system is shown in Fig. 3, including the endoscope, two articulated instruments, the base and support structure, manipulator links, and all actuation motors. The base ring rotation and support structure inclination motors move the endoscope and instruments together as a unit, while the rack-and-pinion motors and the manipulator link and shaft rotation motors move the instruments and endoscope independently. The endoscope is clamped directly to its rack and pinion mechanism and each instruments is connected to the its rack and pinion mechanism by two actuated links and a universal joint. The instrument shafts cross at the insertion site and are bent back inside the body for triangulation and so that they are both visible to the endoscope, in a similar configuration as typical manual LESS surgery. A robotic articulated instrument from our laboratory is shown in Fig. 4.

The actuator gearmotors are integrated directly into the linkage joints without any cable, belt, or remote center linkage mechanisms, resulting in a simple and compact system. Brushless DC gearmotors from 16 to 24 mm in diameter have been found to provide sufficient torques to manipulate robotic surgical instruments for typical operations of grasping, cutting, and suturing, and are available in autoclavable and immersable versions. The complete system in the vertical position is 180 mm in diameter, 330 mm high, and 5-7 kg. The endoscope can be rotated 360 degrees and inclined from the vertical to within 15 degrees of horizontal, with an insertion range of 200 mm. The instruments can be angled up to 32.5 degrees from the endoscope shaft at their minimum insertion and up to 44 degrees at the maximum.

The pictured system restricts the instrument on one side to a greater insertion depth than the endoscope since their rack-and-pinion actuators travel on a single rack. This is not a significant hindrance to the utility of the system however, as it is hazardous to manipulate an instrument when it is not visible to the endoscope.

III. CONCLUSIONS AND FUTURE WORKS

Fabrication of the designed single-site system will proceed during spring 2012, to be completed in early summer. The teleoperation masters and motor controllers of the current University of Hawaii surgical robot system can be used with the new system directly, and the existing teleoperation and control software can be used with the new system with minor modifications.

We plan to proceed with preclinical trials, using the new system to perform skills training tasks established by the Society of American Gastrointestinal and Endoscopic Surgeons as the Fundamentals of Laparoscopic Surgery (SAGES FLS), a standard set of tasks used as a benchmark in surgical training. The tasks will be performed by untrained volunteers and by trained medical students and surgeons.

The system is designed to be modular with interchangeable components. We aim to make it possible to operate other commercial robotic articulated instruments such as JAiMY from Endocontrol SA and the VeSPA instruments from Intuitive Surgical Inc. using our teleoperated manipulator system.

REFERENCES