

# EVOLAP, an Active Laparoscope Positioner devoted to Ergonomics

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## INTRODUCTION

Ergonomics has a major influence on the acceptance of a robot in the operating room, as space and time are highly valued in today's surgery. Several laparoscope positioners have been developed since the mid-90s, so as to solve problems posed by manual camera handling [1]. All these devices allow the surgeon to control the camera displacements *via* a 'hands-free' interface (e.g. voice recognition, head tracking, miniature joystick), and offer improved image stability at rest [2].

Nevertheless, current systems suffer from several drawbacks. They are generally space-consuming around the table or above the patient's abdomen. Most have mechanical axes of rotation that require accurate alignment with the incision. Consequently, the position of the robot cannot be chosen freely by the surgeon. Set up and break down operations must be performed carefully, and increase total operative time. In addition, the motions of these systems are limited in range and quite basic, mainly due to their electromechanical structure and the control method or device. In most cases the laparoscope moves at a constant angular speed and the available directions are simply 'left-right', 'up-down', and 'in-out', without any possibility to combine them in real-time teleoperation so as to obtain more natural oblique displacements towards the target. Lastly, due to their kinematics, laparoscope motions are not always identical to natural motions obtained by hand manipulation with direct visual feedback from the monitor. This difference between actual image shifts and the ones expected by the surgeon may induce confusion as to the actual laparoscope configuration, and disorder hand-eye motions.

Although active scope holders do have the potential for improving ergonomics of laparoscopy, the numerous weaknesses of existing devices tend to slow down their acceptance and their spread in hospitals.

## MATERIALS AND METHODS

From the above analysis, we drew up a list of important requirements in order to design a new robot that would meet surgeons' needs and expectations. The distal tip of the laparoscope (inside the peritoneal cavity) needs to be moved through a large workspace, although the robot should be compact and its motions not too cumbersome. The surgeon should be allowed to place the robot in a convenient position, without being constrained by the

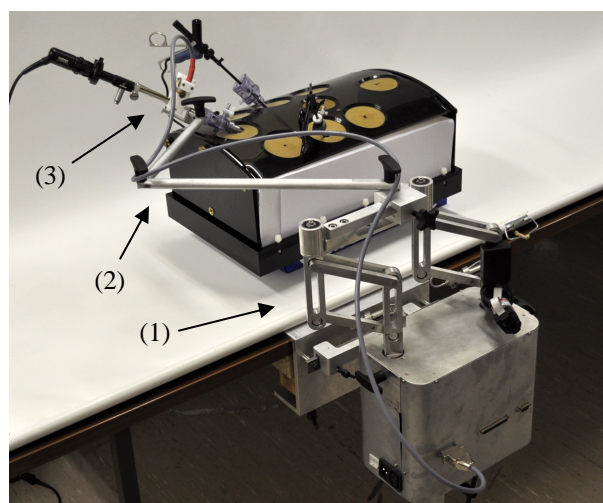
trocar position, so as to allow all the team members to choose their own position freely. Installation and set up should be fast and easy. Finally, the robot should be controlled through an ergonomic and intuitive interface that provides an immediate response and offers more capabilities than only basic motions at constant speed.

With the help of practitioners, these needs were translated into weighted criteria used subsequently during the design process to compare solutions and select the optimal one objectively. The proposed design consists of three main components (Fig. 1):

(1) A main 2 degrees-of-freedom (DOF) remote manipulator is fastened on one of the lateral table rails through a height adjustment mechanism. Table mounting allows a change of table set up during the procedure without requiring any robot adaptation.

(2) A passive arm connects the end-effector of the main manipulator to the laparoscope *via* two orthogonal passive joints. It has also several joints that can be unlocked for adjustment during installation, once the main manipulator has been secured on the table in a convenient position. The main manipulator induces angular motions ('pan' of the video images) from the table side and the rigid arm transfers these swivelling motions to the laparoscope.

(3) A local zoom device located at the distal end of the passive arm translates the laparoscope into the cannula ('zoom') without any displacement of the arm.



**Fig. 1** Overview of the prototype of EVOLAP, an active laparoscope positioner devoted to ergonomics.

This decoupled architecture is capable of producing large intra-abdominal displacements of the lens with limited robot motions above the patient's abdomen.

The main 2-DOF remote manipulator has a particular kinematic structure, consisting of several orthogonal parallelograms, which *translates* the end-effector onto the surface of a half-sphere. This motion can then be reproduced above the patient's abdomen without the need for any alignment between the robot and the incision. Priority can thus be given to the optimal placement of the surgical team around the patient, the robot being positioned conveniently next to them on the suitable side of the patient (e.g. on the right side of operating workspace for a right-handed surgeon with his major hand above the table), regardless of the insertion point of the laparoscope, or the type of procedure. A PCT patent application describing the general decoupled architecture of the robot and the particular kinematics of the main manipulator was filed in 2008 [3].

An omnidirectional and proportional joystick, attached to the minor-hand instrument, allows the surgeon to control the motions of the robot in real-time. Compared to voice or head control, this input interface offers some interesting functionalities. It can combine 'left-right' and 'up-down' motions to pan the video images in any direction, and the speed of the laparoscope can be adjusted by tilting the joystick more or less.

A kinematic modelling of the motions achieved by existing laparoscope positioners highlighted the occurrence of inaccurate image displacements or wrong camera orientation in specific robot configurations. An original definition of operational coordinates was proposed to remedy this important ergonomics issue.

The main manipulator is also equipped with a static balancing spring mechanism, and a high efficiency transmission was designed to ensure back-drivability, affording the possibility to move the laparoscope either with the joystick (tele-operated active mode) or by hand (manual passive mode) with a force equivalent to the one required by classic passive devices. The total weight of the device is less than 10 kilograms, making it easy to carry and to mount on the table. A complete technical description can be found in [4].

Several phantom trials were carried out during the design process to assess the duration of installation, and to tune the controller parameters. Finally, a first clinical trial was performed to evaluate performances in real practice, as ergonomics and usability cannot be assessed by any other means. Details of experimental *in vitro* and *in vivo* validation can be found in [5].

## RESULTS

The *in vivo* procedure went off successfully and uneventfully. Compactness of the robot allowed all the team members — the surgeon, two assistants, a nurse and a supervising engineer — to stand next to the table and work normally, without being bothered by its presence. Intra-abdominal workspace (ranging from 0° to 80° in 'up-down' direction and software restricted from -50° to 50° in 'left-right' direction for safety) was

sufficient to reach all desired angles and depths, while arm and robot motions did not restrict the surgeon's freedom of motion with his surgical instruments. Speed control and joystick sensitivity helped the surgeon to drive the laparoscope quickly and with precision, and omnidirectional displacements allowed him to navigate easily. The surgeon reported subjectively that image stability was better than ordinary with an assistant, without any spurious motion of the laparoscope.

## DISCUSSION

A novel robotic laparoscope holder has been developed, with special attention devoted to the ergonomics requirements of minimally invasive laparoscopic surgery. A particular robot architecture was proposed to allow large displacements of the laparoscope in the abdominal cavity, although the device is compact and quite lightweight. Its kinematic structure does not require any alignment with the laparoscope swivel point, this allowing the surgeons to choose their own placement without additional constraints.

A first *in vivo* procedure was performed with the prototype and demonstrated the feasibility of the solution. Compactness of the main structure was appreciated. Image stability was very good throughout the whole procedure, regardless of the configuration of the laparoscope and the respiratory motions.

Surgeons found the instrument-mounted joystick very intuitive and more comfortable than other control devices. Whereas voice, head or foot control permits only sequential motions at constant speed, the proposed joystick allows accurate omnidirectional displacements and real-time speed adjustment.

Further *in vitro* experiments should be carried out to quantify the advantages of the robot and its interface, by measuring motion time and path length to reach a target. A series of clinical trials should also be performed by surgeons from various specialities in order to assess usability and measure image stability.

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