Design and Preliminary in Vivo Validation of a Robotic Laparoscope Holder for Minimally Invasive Surgery

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Design and preliminary *in vivo* validation of a robotic laparoscope holder for minimally invasive surgery

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Abstract

Background Manual manipulation of the camera is a major source of difficulties encountered by surgeons while performing minimally invasive laparoscopic surgery.

Methods A survey of laparoscopic procedures and a review of existing active and passive holders were conducted. Based on these analyses, essential requirements were highlighted for such devices. Pursuant to this, a novel active laparoscope manipulator was designed, paying particular attention to ergonomics and ease of use. Several trials on the pelvitrainer and a first *in vivo* procedure were performed to validate the original design of our device.

Results Phantom experiments demonstrated ease of use of the robot and advantages of the intuitive joystick with omnidirectional displacements and speed control. The compactness of the device and image stability were appreciated during the surgical trial.

Conclusions A novel robotic laparoscope holder has been developed and produced. An *in vivo* trial proved its value in clinical practice, enabling surgeons to work more comfortably.

Keywords robot-assisted surgery; minimally invasive surgery; laparoscope holder; *in vivo* trial

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. New surgical techniques, such as laparoscopy, lead to great benefits for the patient but slightly complicate the surgeon's job (1,2). Incisions mirror motions and preclude any direct contact with intra-abdominal tissues. Force perception is altered by friction and scaling, due to the long instruments. Most of all, the surgeon has no direct three-dimensional view of the operative field, and looking at a remote screen makes his line of sight unnatural. As a consequence, the perceptual and visual feedback information is only received indirectly by the surgeon.

Manual manipulation of the laparoscope is a main cause of difficulties encountered by surgeons (2–7). Needing both hands free to carry out the operation, the surgeon has to entrust manipulation of the camera to a colleague, or more often to a little-tested assistant. Communication problems occur from time to time, and a lack of coordination between surgeon and assistant often results in wrong or unwanted picture motions. Holding the camera may also be exhausting in long cases. Due to fatigue and hand tremor, the image becomes unsteady. These spurious image motions are known to decrease performance in goal-directed hand motions such as fine suturing. Furthermore, depth perception, already poor due to the absence of direct stereovision, is decreased, as camera motions are not performed by the surgeon himself. As a consequence, hand–eye coordination is disordered. Temporary losses of focus also happen as the assistant performs other surgery-specific tasks with his other hand. Less attention is then paid to the laparoscope, and the distal lens can hit tissue and get dirty. Finally, the physical presence of the assistant might also be cumbersome in the cramped workspace and reduce the surgeon's freedom of motion. All these problems of ergonomics tend to disturb the surgeon's concentration and cause fatigue and irritation, to the detriment of healthcare quality.

To overcome some of these difficulties, passive and robotic laparoscope holders have been brought to the market over recent decades. This paper briefly summarizes the advantages and drawbacks of existing devices and states the requirements for the development of a novel system aiming to improve the ergonomics of laparoscopy. Our solution is then described, with particular attention being paid to the robot kinematics, so as to induce adequate laparoscope motions. Finally, the first *in vivo* experiment is presented, and further avenues of research are proposed.

Background

Many studies have been conducted over the years to measure the performance of laparoscope holders and to assess feasibility of assisted laparoscopic surgery (3–10). Most of the authors reported that these devices could actually replace the assistant without changing the outcome of the procedure, allowing solo surgery in some simple cases. Laparoscope holders offer a more stable image, making fine suturing easier. They also reduce the number of lens-cleaning actions needed. Camera placement is more accurate than with an assistant, and the average number of camera motions during a procedure is decreased by more than half. Furthermore, surgeons feel less fatigue and can concentrate better on their work, as they do not have to guide the assistant.

Mechanical holders

Passive instrument positioners consist of several bars connected by lockable joints. They are attached to the operating table rail, and their tip holds the endoscope. The surgeon can grasp the holder and move it to a suitable position, after releasing the joints. Devices such as Unitrak and Endofreeze (3,10) (Aesculap, Tuttlingen, Germany), Endoboy (3,6) (Geyser-Endobloc, Coudes, France), Martin Arm (3,10) (Gebrüder Martin GmbH & Co., Tuttlingen, Germany), PASSIST (3,5) (Academic Medical Centre, Amsterdam, The Netherlands) and the automatic camera-holding system (7) developed at the Helmholtz Institute for Biomedical Engineering (Aachen, Germany) are compact and simple to use and offer good image stability for a low price. They are quick and easy to set up and to remove from the table and do not increase operation time. But although manual displacement of the camera is reported to improve depth perception (3), at least one hand is required. The surgeon must then release one or even both instruments to grasp and move the camera. Moreover, some of these devices are equipped with independent brakes on each joint that must be unlocked one after the other to free the laparoscope, interrupting concentration and disrupting the general fluency of the procedure (4). All things considered, passive holders seem more suited to lock a static instrument, such as a retractor, than to allow frequent camera motions (6).

Robotic holders

Active scope holders overcome these limitations. Some of their joints are actuated by electrical motors, so that the surgeon only has to tell the robot where to go via a 'hands-free' interface. AESOP (3,5,8,9) (formerly Computer Motion Inc., Goleta, USA) is voice-controlled; EndoAssist (3,8,9) (Armstrong Healthcare Inc., Acton, USA) is head-controlled with a helmet; LapMan (3,4) (Medsys SA, Gembloux, Belgium) and Naviot (11) (Hitachi Ltd, Tokyo, Japan) use a small joystick mounted on the instrument; and ViKY (6) (Endocontrol Medical, Grenoble, France) can be moved either by a footswitch or by voice control. Although all these devices function properly, they suffer from several drawbacks. They are generally more bulky and heavy than passive positioners. Most of them have mechanical axes of rotation that require accurate alignment with the incision. Consequently, the position of the robot can not be chosen freely by the surgeon, and set-up and break-down operations must be performed carefully, and increase total operative time. Also, if the table is readjusted during the procedure with a robot placed on the ground (e.g. EndoAssist, LapMan), the robot must then be realigned. Furthermore, the motions of these systems are quite basic. Mainly due to the control method or device, the laparoscope moves in most cases at constant angular speed, needing a trade-off between fast motions in broad view and slow motions in close-up, and the available directions are simply 'left–right', 'up–down' and 'in–out', without any possibility of combining them in real-time teleoperation for obtaining more natural oblique displacements towards the goal. Lastly, due to their electromechanical structure, laparoscope motions are not always identical to natural motions obtained by hand manipulation with direct visual feedback. This difference between actual laparoscope motions and the ones expected by the surgeon may induce confusion about the real laparoscope position, and disorder hand–eye motions.

Although active scope holders could really improve the ergonomics of laparoscopy, the numerous weaknesses of existing devices, combined with their expensive price compared to cost-effective passive stands, tend to slow down their acceptance and spread in hospitals.

Materials and methods

From the above analysis, we made out a list of important requirements in order to design a new robot that would come up to surgeons' needs and expectations. First, 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 also be allowed to place the robot in a convenient and ergonomic position without being constrained by the trocar position, so as to let all the team members choose their own placement regardless of the robot position. Installation and set-up should be easy and very quick, and no further adjustment should be required if the height or angle of the table is changed during the procedure. The robot should be controlled through an ergonomic and intuitive interface that gives an immediate response and offers more advanced capabilities, such as complex oblique motions and direct speed control. Finally, giving the ability to move the laparoscope by hand without having to disconnect it from the robot could be useful in some circumstances, such as during initial exploration of the abdominal cavity. It could also help in restoring hand–eye coordination during the procedure.

Pursuant to these requirements, we developed a compact, ergonomic and user-friendly scope holder for providing optimal support to the surgeon.

The device consists of three main components (Figure 1a). A main manipulator (A) is mounted on one of the lateral table rails via a height adjustment mechanism. Its end-effector is linked to the laparoscope by a passive arm (B) via two orthogonal passive revolute joints (nos 16 and 17 in Figure 1b). This arm has releasable joints 13–15 that can be unlocked for adjustment during the installation process. The main two degrees of freedom (DOF) manipulator remotely induces angular motions (pan of the video images) and the rigid arm transfers this swiveling motions to the laparoscope. A local zoom device (C) located at the distal end of the passive arm translates the laparoscope into the cannula to produce the in–out motion (zoom of the video images) without any displacement of the rest of the system. This decoupled architecture is capable of producing large intra-abdominal displacements of the lens with limited motions of the robot above the patient's abdomen. In addition, the main manipulator has an original kinematic structure, detailed below, that allows it to be located in a convenient place regardless of the relative position of the incision.

Detailed robot description

Global architecture

Due to the two passive joints 16 and 17 between the arm and the laparoscope, the robot manipulates the camera like a human being. To pan the video images, the main manipulator *translates* one point of the laparoscope on the surface of a sphere centred on the incision, as depicted by the red arrows in Figure 1. As the laparoscope is naturally constrained to pass through a second point (i.e. the incision), its *orientation* along a radius of the sphere is then passively determined, as with AESOP or LapMan. Other robots, e.g. EndoAssist, ViKY, control all six DOFs of the laparoscope and impose its rotation around a remote centre-of-motion, determined mechanically or

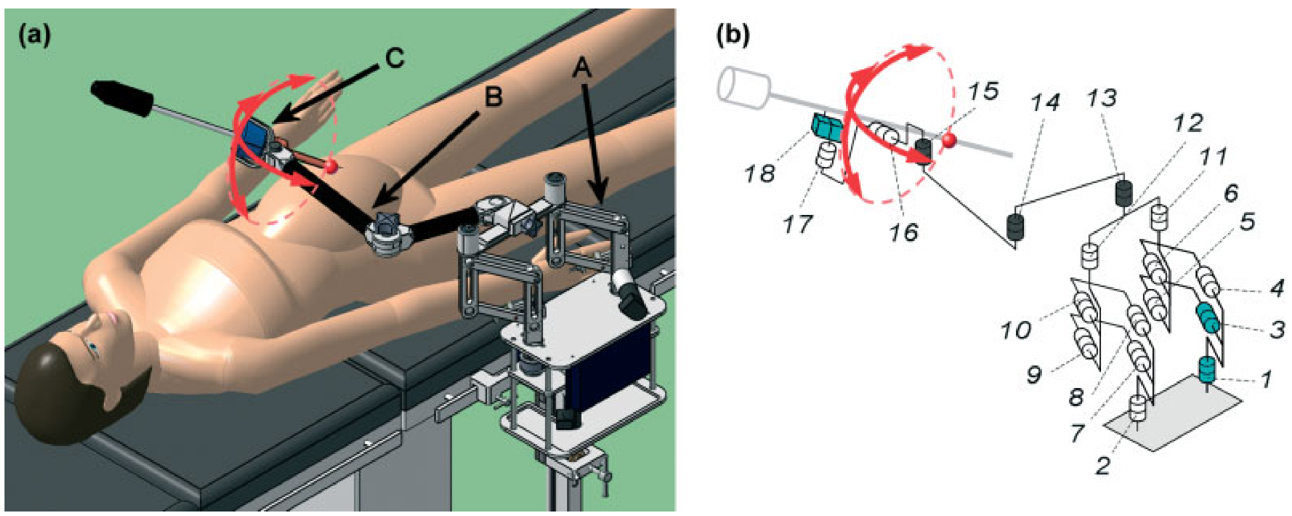

Figure 1. (a) Overview of the device, composed of a main manipulator A mounted on the lateral table rail, a passive articulated arm B and a local zoom device C. (b) Kinematic architecture of the device. Blue joints are actuated, grey joints are locked and white joints are free

by software. These systems must therefore be perfectly aligned with the natural swivel point to avoid injuries to the abdominal wall.

To achieve these laparoscope motions, the main manipulator has a particular architecture, made of several orthogonal parallelograms. Two parallelograms (respectively made of joints 3–4–5–6 and 7–8–9–10) are clearly visible in Figure 1a, b. Their base bars (respectively 3–4 and 7–8) are mounted vertically on the manipulator base through revolute joints 1 and 2. Their end bars (respectively 5–6 and 9–10) are linked by the end-effector of the manipulator that connects joints 11 and 12. Figure 2a represents a schematic top view of the main manipulator. The end-effector length is equal to the distance between joints 1 and 2, so that the two vertical parallelograms (in dark grey) are parallel to each other, and form a third parallelogram (dashed in Figure 2a) along with the base 1–2 and the end-effector 11–12. As the joints of this base parallelogram are perpendicular to those of the vertical parallelograms, the base parallelogram itself is orthogonal to both vertical ones, and all three rotational DOFs of the end-effector are constrained. Although only two orthogonal parallelograms are required to lock all rotational DOFs, the other vertical parallelogram is added to increase rigidity without any kinematic function, as both vertical parallelograms are identical in shape and orientation.

Joints 1 and 3 are actuated, and all other joints of the main manipulator are free. When joint 3 revolves, the shape of both vertical parallelograms changes, as moving bar 3–5 is tilted with respect to the fixed base bar 3–4. End bars 5–6 and 9–10 force the end-effector 11–12 to follow a circular trajectory parallel to planes of both vertical parallelograms, but without any rotation. In the same way, when joint 1 is actuated, the base parallelogram changes its shape and the end-effector 11–12 makes a circular translation in a plane parallel to the base of the main manipulator. The general shape of the main manipulator workspace is therefore the surface of a sphere, obtained by a combination of these orthogonal circular translations along sort of meridians and parallels.

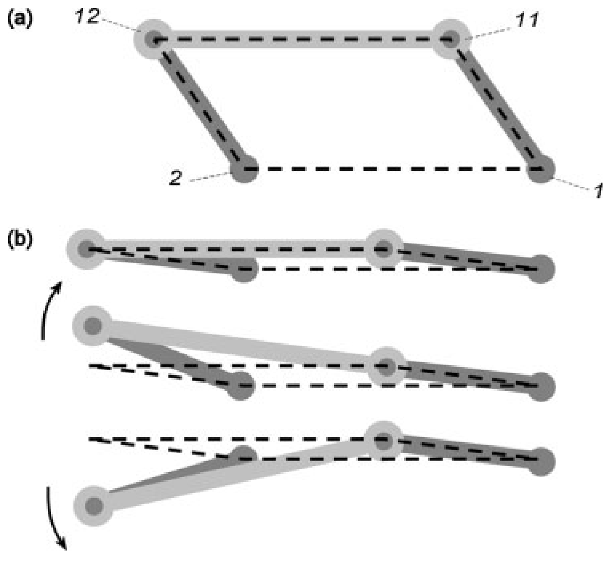

Figure 2. (a) Schematic top view of the main manipulator, showing a horizontal parallelogram (dashed) made of the end-effector 11–12 and projections of vertical parallelograms 1–11 and 2–12. (b) Singular configuration of the parallelogram, which acquires locally a second DOF, decreasing rigidity

The adjustable arm is used to reproduce these circular translations on the surface of a remote sphere whose radius is equal to length of moving bar 3–5. At the beginning of the procedure, the height of the main manipulator and the shape of the arm can be adjusted in order to place the centre of this remote sphere onto the incision. When the laparoscope, passing through the incision, is connected to the arm via passive joints 16 and 17, its longitudinal axis is kept parallel to the moving bars. Any motion of the end-effector will make the laparoscope swivel around the incision and pan the video images. Priority can thus be given to the optimal placement of the surgical team around the patient, the robot being positioned conveniently next to them, regardless of the insertion point of the laparoscope or the type of procedure. A PCT Patent application (17) describing the device and its mechanical architecture was published in December 2008.

Specific embodiments

Normally, when one joint of a parallelogram is locked, as it has only one DOF; all other joints are also determined and the parallelogram is rigid. However, when two consecutive bars are aligned, the parallelogram lays in a particular configuration called ‘singular configuration’. This is shown in Figure 2b, where both vertical parallelograms are aligned with the end-effector. In this case, the base parallelogram is singular and has a second local DOF: even if joint 1 is locked, all other joints are locally free to move, decreasing rigidity dramatically. To avoid this local failure and maintain rigidity, a second joint must be controlled using actuation redundancy (a second motor) or a mechanical system has to synchronize two joints. Two mechanical solutions were investigated. In Figure 3a, a fourth parallelogram 1–2–1′–2′ (dotted) was added, with bars 1–1′ and 2–2′ orthogonal to vertical parallelograms. In this way, this fourth parallelogram is fully open and rigid when the base parallelogram is closed and singular. A top view of the prototype of this solution is depicted in Figure 3b. A second idea uses a timing belt to synchronize joints 1 and 2 (see Figure 3c), so as to maintain rigidity in the singular configuration. Adding a parallelogram appears to be a better solution, as it has neither elasticity nor free play. Furthermore, it does not require any adjustment, in contrast to the timing belt, which has to be tightened properly with a tensioning pulley, as illustrated in Figure 3d.

A balancing spring-mechanism (12) has been designed and integrated to both vertical parallelograms to avoid the laparoscope and mobile parts of the robot falling down under their own weight when the actuators are switched off. Manual manipulation of the laparoscope is also made

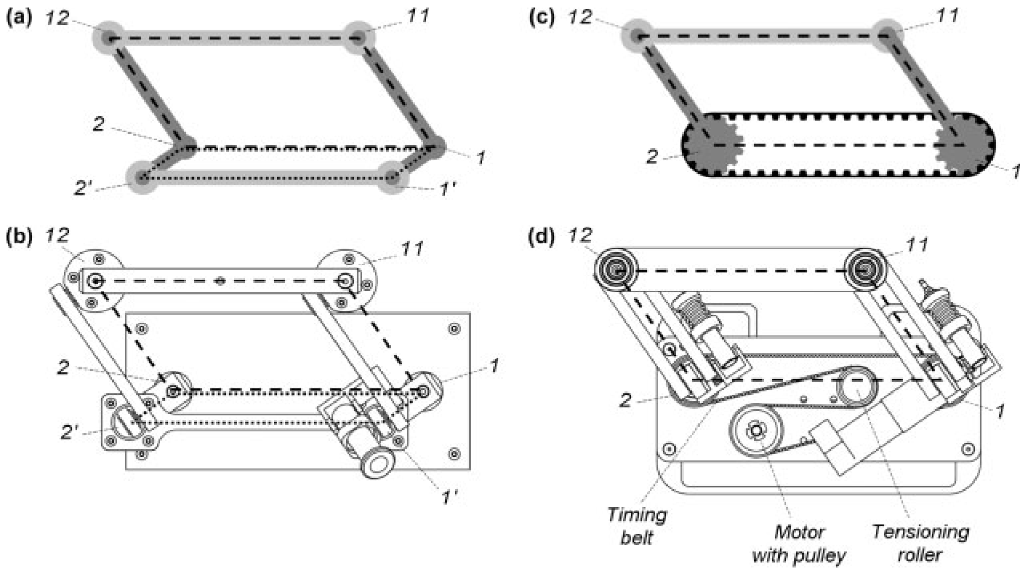

Figure 3. Solutions investigated to avoid local loss of rigidity due to singularity. (a) Schematic top view of reinforcement parallelogram 1-1′–2-2′ (dotted). (b) Implementation of the reinforcement parallelogram. (c) Schematic top view of timing belt that synchronizes consecutive joints 1 and 2 of the horizontal parallelogram. (d) Implementation of the timing belt, with tensioning roller and actuator equipped with a third pulley to run the belt

easier, as the surgeon does not feel the weight of the moving parts.

Two electric motors, with gearbox and encoder, are used to actuate the main manipulator. The first motor assembly is equipped with a pulley and runs the timing belt that synchronizes both joints 1 and 2 of the base parallelogram (see Figure 3d). The second motor assembly is mounted directly on joint 3, as seen on Figure 4, which presents the active prototype of main structure.

To compute the required actuation torques, the main manipulator was modelled as a multibody mechanism, using a symbolic approach (13), with MBsysPad, MBsysLab and Robotran softwares. Motion simulations were then performed with Matlab, along different trajectories covering the entire end-effector workspace. The maximum desired laparoscope speed was 1.05 rad/s (60°/s), which is much faster than existing devices. We over-dimensioned this performance on purpose, so as to determine the required laparoscope speed experimentally without being technically constrained. The maximum desired acceleration was 5.24 rad/s^2 (0.2 s of acceleration time from rest to maximum speed) to allow an immediate response. The computed required torque was 3.5 Nm and the maximum speed of the actuated joints was 6.28 rad/s (60 rpm).

Maxon EC-max 30 40W 12V brushless motors were chosen, in combination with a GP32 three-stage planetary gearbox with a reduction ratio of 132 : 1, and HEDL5540-C02 encoders with 100 pulses/revolution.

The complete main structure weighs <7 kg, including table mounting and height adjustment mechanism, allowing a nurse to carry it easily to and from the table.

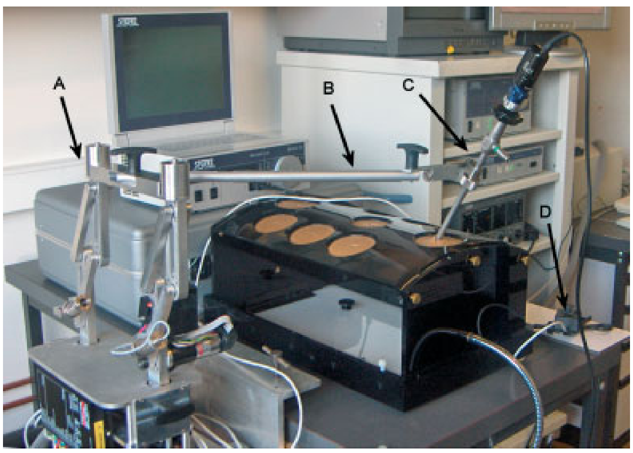

Figure 4. Prototype of the device on the pelvitrainer, composed of main active manipulator A, simplified arm B, manual laparoscope clamp C and miniature joystick D mounted on a surgical instrument

Overview of control device and method

Human–machine interface

The robot is controlled via a miniature joystick clamped onto the minor hand instrument. The prototype has the size of a matchbox, as seen on Figure 4. This first version is not autoclavable and is dedicated to one particular instrument, but an industrial version should overcome these limitations. This interface is believed to be easy to use, reliable, and to react immediately to order.

The joystick is made of orthogonal potentiometers that produce two electrical signals, whose tensions are proportional to the tilt angles in the left–right and up–down directions. As explained in Figure 5, these signals, representing the desired laparoscope angular speeds, are sent to a Windows computer through a dSPACE DS1102 DSP controller board. A control algorithm, designed in Simulink with RTI, runs on the DSP and uses the joystick signals to compute in real time the

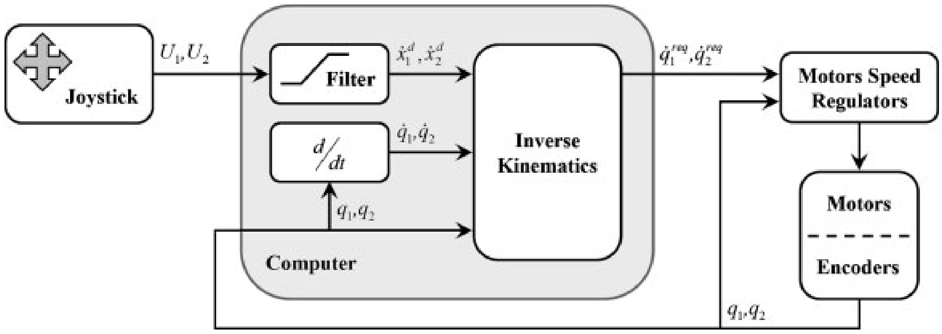

Figure 5. Overview of the control scheme of the robot

required motor rotation speeds. In this algorithm, signals are first treated by a first-order Butterworth low-pass filter, to smooth accelerations and avoid image vibrations when the laparoscope starts or stops moving. They enter the inverse kinematic model of the robot, which computes required joint velocities. These required joint velocities are sent to Maxon DES50/5 servoamplifiers, which regulate the actuator speeds.

A graphic user interface has been developed with dSPACE ControlDesk, which displays robot data (e.g. motor speeds, laparoscope angular positions) and allows the surgeon to adjust some parameters (e.g. joystick sensitivity, maximum speed, angular limits to restrict intra-abdominal workspace for a particular procedure).

In addition to the open-loop teleoperated mode, a closed-loop mode has been implemented for automatic return to a user-memorized position. Once activated by the surgeon, a bang-bang trajectory is planned in joint space, with synchronized velocity saturation and continuous second-degree polynomial acceleration, as described in (14). During displacement towards the desired position, computed reference joint velocities are adjusted by proportional feedback of the error between actual and planned position.

Definition of user-orientated coordinates

One major ergonomics issue of laparoscope manipulation is the selection of the axes of rotation controlled via the joystick. The simplest solution lies in assigning each motor to one joystick direction. The inverse kinematic model is then straightforward: the first motor is activated when a left–right motion of the image is ordered, and an up–down command actuates parallelograms 2 and 2′. The ViKY robot uses this direct drive control, which works well when the laparoscope is parallel to the table. Both actuated axes of rotation are then perpendicular to the longitudinal axis of the laparoscope, and are aligned respectively with the vertical and horizontal borders of the monitor. But when the laparoscope is nearly normal to the table, its longitudinal axis is almost parallel to the axis of rotation of the first motor. As a consequence, when the surgeon orders a Left or Right displacement, the image is turned counterclockwise or clockwise on the monitor, instead of being translated (circularly) along horizontal borders as needed.

To overcome this main limitation, a first solution is to command motions in the local frame of the image, i.e. to make the laparoscope swivel around instantaneous axes that are parallel to the monitor borders. Image motions exactly match the surgeon's will, like manual manipulation: the assistant always tries to move the laparoscope so as to follow one border of the monitor. Although this solution seems to be perfectly suited, rotation of the laparoscope around its longitudinal axis must be actuated, as on AESOP. A direct consequence of this actuated rotation is that, after a few motions, the camera could come back to a previous point of view under a different orientation. Surgical instruments entering the image initially through the lower border of the screen would therefore appear from the left border, after the successive up–left–down motions. The surgeon could quickly lose his landmarks, and moving its instruments properly would become more and more difficult.

A good compromise between these two extreme solutions is to use a frame made of the axes of rotation of the two passive joints 16 and 17 between the arm and the laparoscope, as LapMan does. Left–right motions are then always performed correctly along the monitor horizontal borders, as the second passive joint 17 is always perpendicular to the longitudinal axis of the scope. Up–down motions are nearly accurate when the laparoscope remains close to the centre of the intra-abdominal workspace of the procedure (generally the patient's sagittal plane), and only become non-linear close to the left and right borders (e.g. 50° from the sagittal plane). This user-coordinates selection has the advantage that the laparoscope always comes back to a previous position with the same image orientation, as rotation around its longitudinal axis is locked. We decided to implement the last solution, which does not require a third motor for panning the image.

Experimental optimization and first *in vivo* trial

A series of experiments were performed by surgeons on a pelvitrainer, with the active prototype of the main manipulator. It was equipped with a basic passive and a manual laparoscope clamp (B and C in Figure 4) to allow manual translation of the laparoscope during the procedure, the active local zoom being currently under development. Objectives of these phantom trials were to adjust parameters of the robot, especially the maximum laparoscope angular speed, and to check the predicted advantages of omnidirectional displacements with continuous speed control. Four surgeons of various experience in laparoscopy and robotic surgery performed manipulation exercises that required laparoscope displacements. The joystick was used firstly in advanced mode (i.e. omnidirectional motions and proportional speed) and secondly in basic mode (i.e. only four directions at constant speed), for comparison. Trials were video recorded, with comments from the surgeons about the use of the robot and the joystick.

After these preliminary optimization experiments, we decided to realize a first clinical trial, to assess in real conditions the pertinence of our overall solution. Our goal was only to focus on the general design of the robot and to identify necessary improvements.

A laparoscopic salpingectomy (i.e. the removal of a Fallopian tube) was therefore performed on a patient with the active prototype of the main manipulator. The device was mounted on the lateral rail of the operating table and covered by a sterile transparent plastic bag (see Figure 6a). A basic passive arm was secured on the end-effector of the robot. It was equipped with a manual laparoscope clamp to allow manual translation of the laparoscope during the procedure, the active local zoom being currently under development. The joystick was attached on the minor-hand instrument, which is less often changed than the major-hand instrument. The installation procedure took about 5 minutes, due to a problem encountered during fixation of the joystick prototype, which could not be sterilized and was therefore covered by a plastic camera bag. Normal installation should require about 2 minutes, as measured during set-up trials reported in (15).

Results and Discussion

During *in vitro* trials, all surgeons highlighted the ease of use of the robot. Only a few minutes were required to get the feel of the joystick. Advanced control mode was found to be more intuitive than basic motions at constant speed. Panning the image in the desired direction to reach the target in a straight line seemed much more natural and efficient than moving step by step horizontally and vertically. Speed control was also very useful, allowing long and fast motions in general view, and slow and accurate corrections in close-up. The maximum desired angular speed was in the range 10–30°/s, depending on the surgeon's previous experience with robotic scope holders. The controller should therefore allow the surgeon to adjust the maximum allowed speed.

The *in vivo* procedure went off successfully and uneventfully. Although there were five persons around the table, as shown on Figure 6b, the compactness of the robot allowed all the team members – the surgeon, two assistants, a nurse and a supervisor engineer – to stand next to the table and work normally without being bothered by its presence. The intra-abdominal workspace was sufficient to reach all desired angles and depths, while the 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. Non-correspondence of the up–down motions with the image frame was hardly noticed by the surgeon, and omnidirectional displacements allowed him to navigate easily in the abdominal cavity. Image stability was better than the ordinary situation with an assistant, and respiratory motions did not produce any disturbing motion of the laparoscope. No lens cleaning was required, although a few unwanted motions occurred during the beginning of the procedure; the surgeon was not used yet to the bulk of the joystick and let his finger rest on it, but he

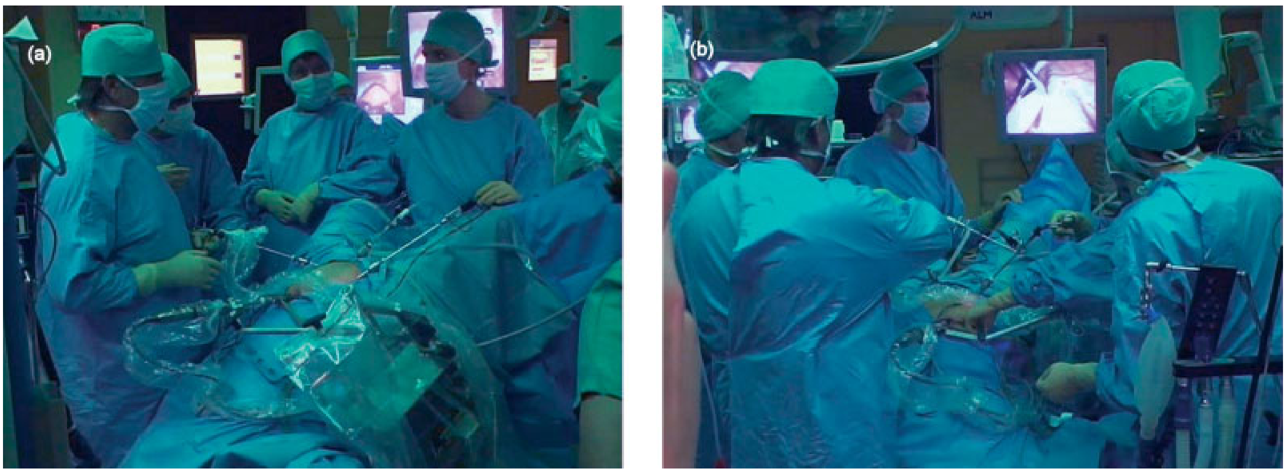

Figure 6. First *in vivo* procedure. (a) Main structure mounted on the lateral rail of the table and covered by a sterile plastic bag. (b) The compactness of the robot allows all the team members to stand next to the table and work normally without being bothered by its presence

learnt rapidly to remove his finger after a motion to avoid this problem. The passive mode with actuators switched off was useful at the beginning of the procedure, during the installation of the robot and the initial exploration, and the camera was easy to manipulate by hand.

Conclusion and future work

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, so as to let the surgeons choose their own placement without additional constraint.

A first *in vivo* procedure was performed with the prototype and demonstrated feasibility of the solution. The compactness of the main structure was appreciated. Image stability was very good during the whole procedure, regardless 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 permit only sequential motions at constant speed, the proposed joystick allows accurate omnidirectional displacements and real-time speed adjustment. Further experiments should be carried out to quantify the advantages of this interface. This assessment could be performed as proposed by Yavuz *et al*. (16) and Nebot *et al*. (9) to measure the total displacement time using various input devices.

Further work will include the prototyping and testing of the active zoom device and the passive articulated arm. A revised version of the main manipulator should also be produced, in order to include some design improvements. A fourth reinforcing parallelogram should be used instead of a timing belt, and the second motor should be placed in the base, with a remote transmission to both vertical parallelograms. An autoclavable joystick is also required, with the possibility of securing it to any laparoscopic instrument.

Finally, more clinical trails should be performed with the complete device in various surgical specialties, for gathering quantitative and statistical data (e.g. total operative time, set-up and break-down times, number of laparoscope displacements), so as to confirm the impressions and preliminary results of the first *in vivo* procedure.

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