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# DEVELOPMENT OF A TELEROBOTIC CAMERA MANIPULATOR FOR LAPAROSCOPIC SURGERY

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Abstract: This paper presents a robotic assistant to help surgeons in minimally invasive surgery. The system provides the direct control of the camera positioning inside the abdominal cavity, by both surgeon voice commands and remote teleoperation. This prototype does not require any modification of a standard operating room (furniture or surgery tools) for its installation and its application in operations. The system has been tested by using patient simulators, and *in vitro* tissues. *Copyright © 2002 IFAC.*

Keywords: Medical applications, manipulators, teleoperation, robot kinematics.

## 1. INTRODUCTION

During the last years, a new field has attracted the interest of robotic researchers. Minimally invasive techniques, such as laparoscopy, have grown as a very suitable domain for robotic systems. In these procedures, the surgeon only uses the visual feedback information provided by a camera attached to the endoscope. Thus, the surgeon manoeuvres the laparoscope and video camera within the abdominal cavity to explore the anatomical structures and their pathologies. Since these procedures can last up to two (or even more) hours, the camera image can suffer a significant loss of stability. Focusing the point of interest can also become a difficult task. In this scenery, a robotic aid, being able to move the laparoscopic camera according to surgeon’s voice commands (allowing him or her to use both hands in the surgical procedure itself), would become a very helpful tool in the operating room.

## 2. PROBLEM STATEMENT

Laparoscopic techniques involve the use of long stem instruments through small incisions in the abdominal wall of the patient. A special camera, whose optic penetrates as well into the abdomen, helps the surgeon to manoeuvre the instruments in order to complete the procedure (Satava, 1998). Thus, when developing a robotic aid, we have two possibilities: moving the instruments or moving the camera. Every one of these options follow a different target: robotized instruments can help us to achieve telesurgery, moving the surgeon from the operating room to a distant site; a robotic camera, however, can improve coordination and efficiency, and release a second surgeon (the one who moves the camera) to help the main surgeon, or to carry out another procedure in a different operating room.

A review of the literature can show different ways of facing the development of a laparoscopic assistant. In 1995 Taylor *et al.* proposed a complete system, including a manipulator, a special end-effector to carry the laparoscopic camera and a new control strategy. The orientation of the camera through the incision was decoupled of its positioning. An interface based on an instrument-mounted joystick, for voice-recognition system were not very capable at that moment.

Green, at SRI International (1995), developed a different concept. The target of this system was to explore the possibility of a telesurgery scheme, not only suitable for minimally invasive surgery but also to open surgery as well. This telesurgery concept was later enhanced and taken to a commercial stage by Intuitive Surgical’s Da Vinci system (Guthart, 2000).

The HISAR system (Funda, 1995) presented a new configuration of the manipulator. The proposed one was a 7 dof robot mounted on the ceiling. Two of the orientation axes were passive, to grant free compliance with the entry port. Since this point acts as a fulcrum, it is necessary to have an accurate knowledge of its position to move the camera with precision. In order to achieve this, a re-estimation procedure of the pivoting point is proposed.

Hurteau (1995) proposed a system based on a industrial manipulator, modified by means of an universal joint between the end-effector and the camera holder.

The system of the Universitat Politèctica de Catalunya (Casals, 1996) goes a step beyond and shows a motion control system able of moving the camera following the movements of the instruments. This system is based on a SCARA industrial manipulator modified with an universal joint in the end effector. An extension of this device permits to clear space near the stretcher since the robot does not need to be placed right beside it. The control of the camera is achieved through a computer vision system that tracks special marks on the instruments.

The Computer Motion Aesop (Wang, 1996) is a commercial system intended to move the camera according to the commands of the surgeon, first through a pedal and after through a speech recognition system. It is a 4 dof robot attached to the stretcher, and presents an end-effector with three axes (two passive and one active). Many surgical procedures have been completed using this system, and it has received the FDA-approval.

Another commercial device is the Laparobot (Dowler, 1996) by EndoSista. The orientation is obtained thanks to a remote centre of rotation scheme. The robot has to be placed over the patient in such a way that its centre of rotation coincides exactly with the insertion point.

## 3. ROBOT KINEMATIC DESIGN

The main purpose of the proposed system is to help surgeons by moving the camera according to their commands. No instruments are intended to be robotized at this stage. Moreover, completion of this target should meet the following requirements in order to be a useful solution:

1. The resulting system should avoid (or at least minimize) modifications on a standard operating room.
2. It should not be bulky.
3. It should be safe.
4. Surgeons should command the movements easily.

According to this requirements, the first step was to choose a kinematic configuration. As it can be seen in the related literature, most of the systems -if not all- separate the problem of positioning from the problem of orientation. This way, we consider two different problems:

1. Vertical motion of the wrist movement plane by keeping this plane parallel to the stretcher (translation along the Z axis of the global robot coordinate frame)
2. Motion along the wrist movement plane (combined translations along the local $X_c$ and $Y_c$ wrist axis).

In order to accomplish the motion in the horizontal XY plane by keeping the camera orientation, we conclude that the standard RR planar manipulator is appropriate. This arm is mounted on a monocarrier platform. A double parallelogram structure would have been another possibility for the RR part of the robot. However, it would have added weight and less accuracy (Taylor, 1995). The only advantage of the parallelogram design (the availability of more room for encoders and other sensors) can be easily compensated in the RR manipulator through a proper design of its joints.

The length of the two elements of the RR manipulator have been computed by studying the camera workspace outside of the abdominal cavity when the optic is inserted through the trocar. Fig 1 shows the camera positioning outside limits, defined by a minimal insertion length of the optic through the trocar with the maximal deflection angle of 75º. This

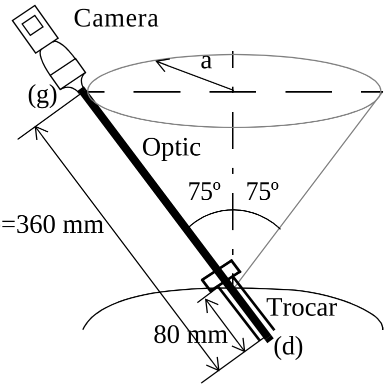

Fig 1. Optic workspace.

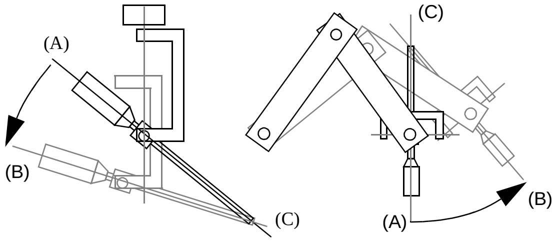

Fig 2. Horizontal and vertical movement

cartesian workspace must be contained inside the robot workspace. This constraint determines the size of the arm.

The orientation problem can be solved in two ways: through passive axes and through mechanically constrained joints. The last solution, though is intrinsically safe, involves a usually bulky structure that has to be placed over the patient. This way, it can restrict the surgeon's freedom of movement, so this possibility was discarded in an early stage of the design (Muñoz and others, 2000). Thus, our proposed system achieves a proper orientation of the camera through passive axes. The first of these axes is disposed parallel to the actuated joints (rotation around the Z axis), allowing the camera to turn around the axis of the inverted cone of its cartesian workspace. The second passive joint (rotation around the X axis) completes the degrees-of-freedom that the camera needs to comply with the required workspace. Fig 2 shows a horizontal movement of the robot arm from point A to B. In this situation, the optic pivots at the trocar insertion point C thanks to the holder Z rotation. Similarly, the vertical movement of the arm is possible due to the X rotation of the holder.

Fig 3 shows the cartesian workspace of the camera related to the resulting workspace of the robot arm. It can be noticed that the workspace of the camera can be located in a wide range of positions inside the robot workspace, thus allowing the system to be placed according to the necessities of every case.

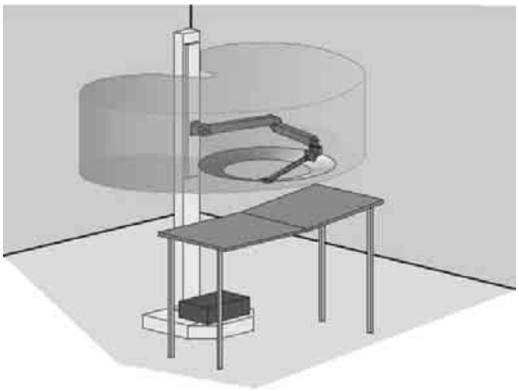

Fig 3. Workspace of the camera related to the workspace of the arm

## 4. THE LOCAL-REMOTE CONTROL SYSTEM

The overall scheme of the shared control system of the robotic assistant is shown in Fig 4. As it can be seen, the robot arm can be commanded both local and remotely by means of high level basic camera movement instructions. The local user (surgeon) interface allows to use spoken commands. The remote user (experienced/mentor surgeon) can see the endoscopic video image and interact with the local surgeon by means of an overlaid graphical annotation system. Also a video-conference channel is available for a more natural communication.

The purpose of this system is to go beyond the limits of the telemedicine and teleassistance applications. In this sense, the first step is to control the camera position inside the patient's body to help the local operator to find the interest area and to show him the suggested procedure. As the robot trajectory generation and feedback control loop are local, the remote system teleoperation is stable (Gómez-de-Gabriel, 1999) under remote supervisory commands.

The communication media between both sites depend on the distance, and varies from low bandwidth internet networks, to dedicated ATM high bandwidth

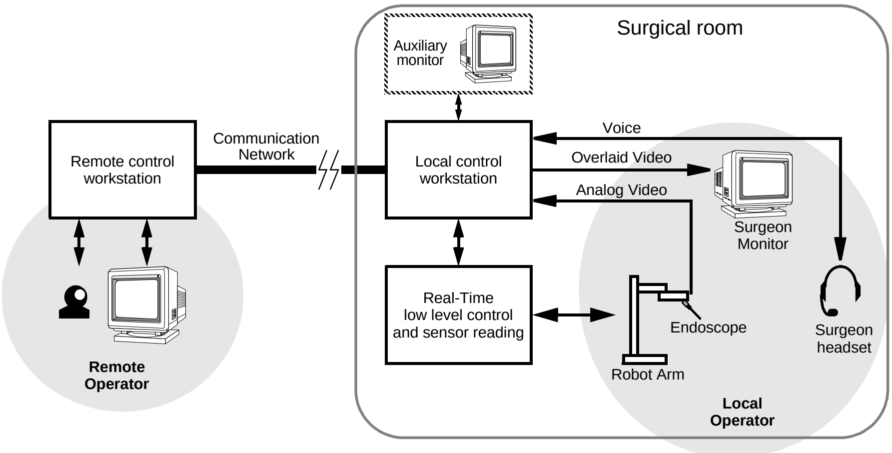

Fig 4. Overview of the local-remote control architecture

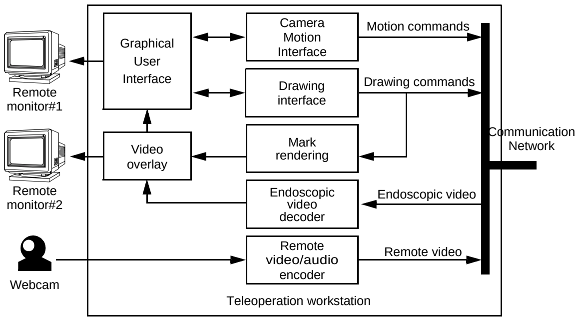

Fig 5. Remote workstation architecture

channels. Shortest distances allow different physical connections for low cost analog video, data and voice channels.

## 5. THE REMOTE OPERATOR INTERFACE

The remote user interface (see Fig 5) is intended for instruction and supervision purposes. In this way, this operator is able to aim the lasparoscopic camera and to advise to the local surgeon by means of a set of overlaid marks. These marks, hand-drawn by the remote operator over the endoscopic image, are displayed both in the local and remote workstations. Moreover, a videoconference link is available between both surgeons.

The dual monitor workstation (see Fig 6) is a Pentium III PC with 128 Mb RAM, a *dualhead* AGP video card from Matrox, running under Microsoft's Windows 98. The main application has been written (designed) in Delphi-4 standard, (Borland). External devices include a Phillips USB webcam and the SpaceBall manual controller (force/torque sensor). Also the NetMeeting application is used for videoconferencing.

The tested video overlay system is based on the inexpensive Brooktree bt878 PCI video capture chip in a 768x576 pixels size 15 bit deep with overlay mode, giving a frame rate of 25 fps (PAL TV system), so slow image acquisition/processing is no longer needed.

Fig 6. The dual remote workstation display

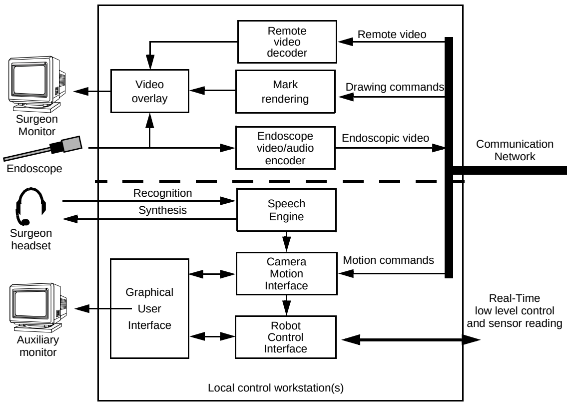

Fig 7. Local workstation architecture

The mouse input device gave the best results due to its easy of use and integration with the operating systems's GUI. So it is used for graphic annotation and for sending robot motion commands. These commands can be issued by means of a single mouse click over the new aim point. Insertion/extraction commands are issued by using the now standard mouse wheel. It is also possible to select special robot commands from a context-sensitive menu, or by using the keyboard. The use of standard devices and computers makes possible to have a teleoperation station in almost any available networked computer.

## 6. THE LOCAL CONTROL WORKSTATION

The local control workstation (see Fig 7) comprises the surgeon interface and the robot control. The first one includes the video and graphical engine as well as the speech recognition and synthesis components. The high level robot motion control translates camera motion commands into joint coordinates as the references for the low level real-time joint controller.

This computer system is also a Pentium III PC running Windows 98 provided with a dual video system (AGP and PCI Voodoo 3-300). The main display offers a 768x576 pixels overlay surface and draws the remote marks. The second display provides technical information about robot status, position and control at the different control levels, which is mainly used by the engineers during the development stages. The main screen is also used to display the low-resolution videoconference system with a view of the remote operator.

A reduced set of intuitive commands relative to the camera coordinate system ("Move Up", "Move Left", "Move Out",...) can be trained for the surgeon voice. The voice recognition system is accomplished by means of the command recognition ActiveX component. Components for voice synthesis have also been used in order to provide convenient user information about command completion.

The local video overlay system is implemented by using the above mentioned bt878 PCI analog video-capture chip because, most commercial laparoscopic camera systems provide analog (S-video/composite) outputs. Other benefits are the low cost and the absence of compress-decompress delay which could difficult the visual feedback control of the surgeon tooltip.

Path generation and tracking is performed by concurrent high priority threads. As this is not a real-time operating system, real-time constraints are soft, and response times are not warranted. For this reason, low level joint control of the three active degrees of freedom are performed by external special purpose microcontrollers (LM628) from National Semiconductors which perform PID control with trajectory generation with *on the fly* update of parameters and trajectory. The power amplifier is an H-Bridge (LMD 18200) capable of driving a 3A PWM signal.

For a smart control of the arm movements, a standard parallel port has been used to send references and control parameters. The PC printer port in EPP mode (bi-directional with automatic handshake control) delivers over 1.5 Mb per second.

## 7. EXPERIMENTS

Two different types of experiments have been carried out, to test the motion control and the teleoperation capabilities.

According to motion control, a cartesian trajectory planning has been implemented. a cartesian planning has been chosen to accommodate motion to surgeon’s commands, which are referred to the laparoscopic camera. Generated trajectories are linear, with a parabolic velocity profile. This trajectory planning was firstly applied to the tool origin, instead of to its end. Experiments have demonstrated that motion control performance was appropriate for our task. Fig 9 shows planned versus actual trajectory -on X, Y, Z axes- of the camera origin during a test. Data was acquired during an *in vitro* experiment, and it corresponds to a single movement. It can be noticed that there is a small deviation in the camera positioning. However, it was only perceived through the curves, and no performance degradation was reported by the surgeon in charge of the experiment.

As it has been mentioned in section 5, the low level control performs a trajectory generation. Thus, the high-level cartesian planning had to be adapted to avoid interferences due to the velocity micro-interpolation which takes place in the microcontrollers.

In addition to the previously mentioned experiments focused on the trajectory planning, another type of test was carried out to check teleoperation capabilities. A surgeon was located in the operating room while a second one, in a different laboratory, gave advice

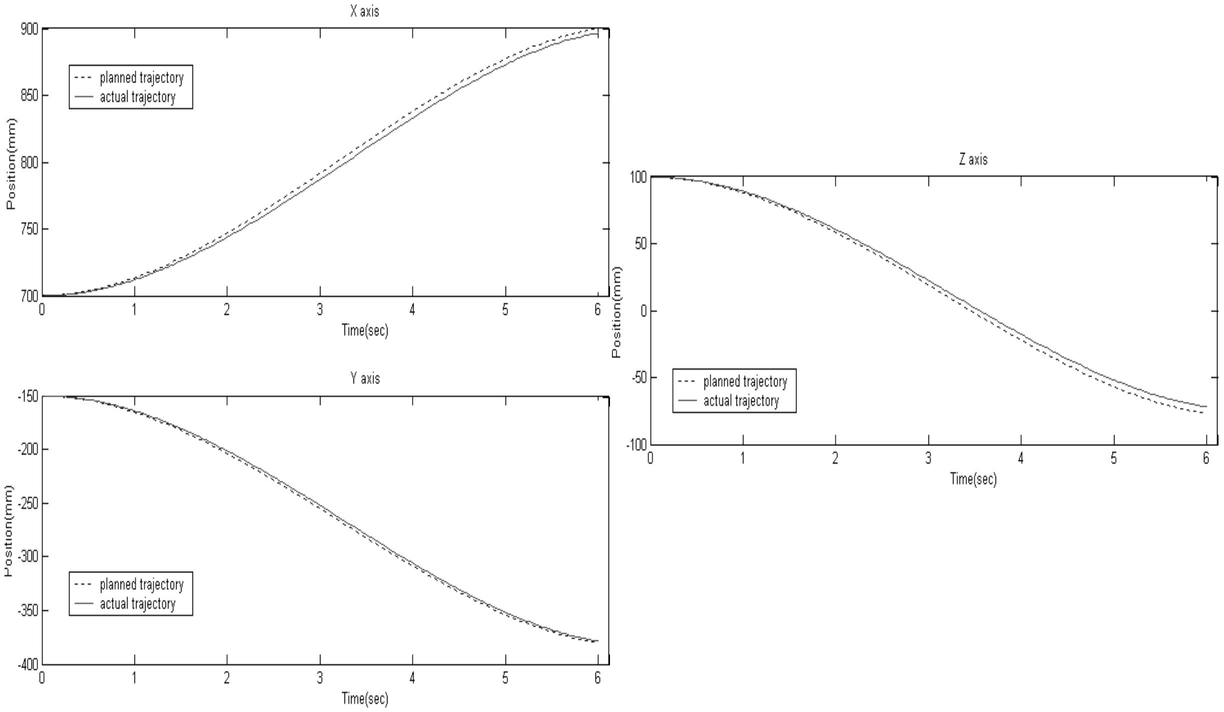

Fig 8. Planned versus actual trajectory, on X, Y, Z axes, of the camera origin

about the procedure through the remote workstation. The task that the local surgeon had to complete consisted of a set of cuts and sutures on *in vitro* tissue. The remote surgeon suggested the procedures to be carried out by means of the overlaid marks, and, if necessary, he could take control of the arm to point the camera on a certain area of interest. Quantitative results about the performances of the system are very difficult to obtain. The only indicator about it is the satisfaction of the surgeons, which of course is very subjective. Surgeons felt safer having a second opinion. Specially remarkable is the fact that their confidence grew up when an additional videoconference channel was available, so as the local and the remote surgeon could see each other.

## 8. CONCLUSIONS

A new robotic arm has been specially developed as a help to surgeons in laparoscopic surgery and telementoring (Fig 10). It requires no modifications on a standard operating room. It is light and simple, and hence, expected costs of a commercial version will be low. Its movements do not interfere with the surgeon, though it can manoeuvre the laparoscopic camera as a human assistant does. Moreover, teleoperation capabilities allow cooperation between distant surgical teams.

## 9. ACKNOWLEDGMENTS

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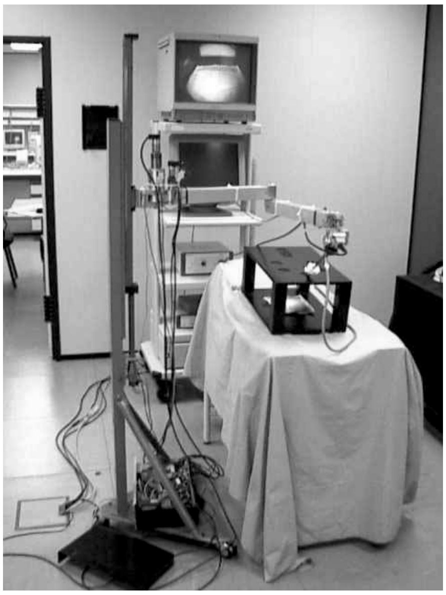

Fig 9. The new robotic assistant.

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