A TELEROBOTIC SYSTEM FOR REMOTE SURGICAL COLLABORATION WITH COMMUNICATION DELAYS

J. Fernández-Lozano(1), J.M. Gómez-de-Gabriel(1), V.F. Muñoz(1), A. García-Cerezo(1) and C. Vara(2)

(1) Instituto Andaluz de Automática y Robótica, Universidad de Málaga
C/ Severo Ochoa 4, Parque Tecnológico de Andalucía
29590, Campanillas, Málaga, Spain
Email: degabriel@ctima.uma.es

(2) I Cátedra de Cirugía, Universidad de Málaga
Facultad de Medicina, Campus de Teatinos
29071, Málaga, Spain
Email: cvara@uma.es

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 this field, one of the easiest application for robotics is the movement of the endoscopic camera. That kind of robots [7][6] aims to move the camera from outside the patient's abdomen to get the image the surgeon needs from the patient's inside. This function has been traditionally performed by a human assistant, following the surgeon orders, for the latter to use his two hands for manipulation tasks. Since these procedures can last up to two (or even more) hours, the camera image can suffer a significant loss of stability, what can be prevented by the use of a robot arm [1]. Besides, it provides accurate movements to locate the optic within the abdominal cavity, and handles the endoscope with a steady hand during the surgical operation.

A secondary use of these systems, and of many other Computer-Integrated Surgery (CIS) applications, is to extend the robot capabilities to the telesurgery paradigm. In general, robotized instruments can help us to achieve telesurgery, allowing an expert surgeon in a remote place (remote surgeon) to take part in the operation with some kind of telepresence devices. In this sense, Green [4] developed a different concept in order to explore the possibility of a telesurgery scheme, suitable not only for minimally invasive surgery but also for open surgery. This telesurgery concept was later enhanced and taken to a commercial stage by Intuitive Surgical's Da Vinci system [5]. Remote control of such inspection systems are, however, especially useful for collaboration between specialist surgeons, for telementoring and for teleproctoring.

Some of the problems for the diffusion of these tools are the need of operating room adaptation for placing the robot, the need of training the medical staff for managing the mentioned tools, their high cost and, in many cases, the complexity they add to the difficult task of surgical intervention.

This work presents a robotic system to assist in laparoscopic surgery moving the camera both locally (by the use of verbal commands) and remotely (which implies working with communication delays). It is a very simple system, what provides a low cost and easy management. Some of the main characteristics of the system are its hardware and software modularity (for a configuration adapted to the application) and its wireless operation, what allows it to be moved manually and at any time, as well as to operate in practically any standard operating room, since it does not have to be plugged in the power supply network. The system also includes wireless voice/data communication media.

SYSTEM OVERVIEW

The system is based on the concept of functional modularity, obtained via some hardware modules. A general scheme of the system can be seen in Fig. 1. There are three main modules: the wireless laparoscopic robot, the teleoperation module and the extended capabilities module. Each one of those units provides one or some functionalities and they can, in principle, be used separately or jointly. The Wireless Laparoscopic Robot (WLR) moves the camera in response to the surgeon commands; the Teleoperation Module allows a remote surgeon to collaborate in, or to surpervise, the operation; and the Extended Capabilities Module provides the connection of the system to the exterior, both with other manufacturers' equipments and with external data bases.

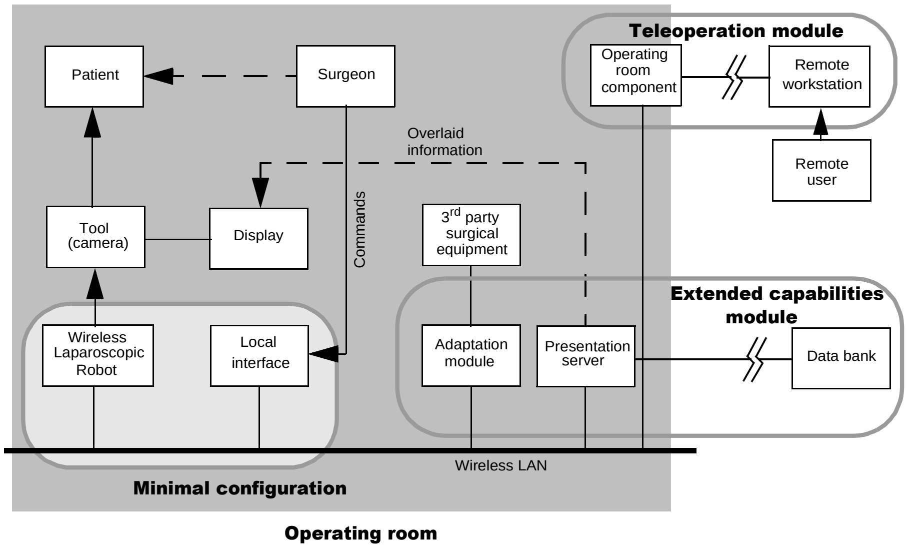

Fig. 1. An overview of the modular concept of the system.

The different modules communicate between them via a wireless communication network, to which other manufacturers' equipments can be incorporated.

The three main modules of the system plus the local surgeon interface are described below.

Wireless Laparoscopic Robot

This is the main element. It is a light manipulator, with three active DOF and two passive DOF, moving the laparoscopic camera (see Fig. 2). The controller is integrated in the robot base and, by its side, there are two batteries providing the power supply of the set. The surgeon has a wireless microphone through which he sends his commands to a local interface, usually a speech recognition system integrated as well in the robot base, even if a joystick, a pedal or another means can be used.

The robot has been designed to occupy a small volume and not to need anchorage to the operating table. Those facts, together with the battery supply and the wireless microphone, make the system to be a wireless system, thus facilitating the integration into the operating room.

The set made up by the WLR and by the local interface forms the minimal system configuration.

Teleoperation Module

This module allows telecollaboration between two surgeons, so that an expert may guide or supervise the operation performed by the surgeon present at the operating room. To facilitate this work scheme, the remote surgeon gets the laparoscopic image, on which he can make marks and comments. That information is sent to the operating room, where it is showed overlaid on the laparoscopic image on the video monitor. The remote surgeon can as well take control of the robot for the camera to show a region of interest. Besides, a videoconference channel allows communication between both surgeons.

The implementation of this module consists of two parts: a component within the operating room and a remote workstation. The first element communicates with the rest of the operating room equipment via the wireless communication network, and with the remote workstation via another communication network, which may be a conventional one. That is, one of its purposes is to act as a bridge between the operating room network and the exterior. Another purpose of this component is to overlay the marks in the laparoscopic image if the extended capabilities module is not present.

The remote workstation consists of a PC. As input interface, the surgeon may use a standard mouse, but some other media, such as master manipulator or *Spaceballs* can be used as well.

a) *b)*

Fig. 2. The Wireless Laparoscopic Robot arm for camera operation: a) the robot arm; b) a trial on an experimental animal.

Extended Capabilities Module

The main component of this module is the presentation server. This element communicates with the local interface, via which the local surgeon can demand information, such as previous patient's explorations or documentation on the procedure in progress. Additionally, if the operating room has surgical equipments prepared for centralized operation, such as those of Storz^{TM} or Stryker^{TM}, the surgeon can also control them via the local interface. In this case, and until a standard on communication of that kind of equipments is not adopted, it is necessary to incorporate an adaptation module.

Local Surgeon Interface

Like most of the robotic surgical assistants, speech recognition has been chosen to provide the command input. It allows a simple way of controlling the robot, avoiding to use hands or feet for this purpose. In addition, this method improves sterilization since it avoids physical contact.

A speech recognition hardware module (Sensory Inc.) has been used, and it is trained to recognize a small set of intuitive commands like "Move Up", "Move Left", "Move Out",... These commands must be trained with the surgeon voice. This module has the capability to play oral messages to confirm to the operator that the instruction has been recognized and that it is to be executed. The module is programmable in C-like language, so it is also in charge of the local interface control, carried out in a very compact and simple way without the need to use PC computers.

TELEOPERATION AND TELECOLLABORATION

When the Teleoperation Module is present, the system can be used in a telecollaboration scheme. The purpose is to offer a tool able of making possible the join work of two distant surgeons, using standard TCP/IP networks. This limitation is intended to provide a wider range of applications, since a larger number of possible remote sites are available. Thus, concepts like telementoring (an expert teaches a novice), teleproctoring (a person supervises another one), or telediagnosis (a remote physician identifies a disease), can take place with the help of the same system.

According to the characteristics of the application, the main feature is to control the camera position inside the patient's body. This way, a remote surgeon can help the local operator to find the interest area. Then, a procedure can be suggested.

To obtain the capability of moving the camera from a remote workstation, a telerobotic architecture has ben designed. This architecture is based in the one proposed in [3], and detailed in [2]. It allows local autonomy in the controlled robot, and since the trajectory generation and feedback control loop are local, the remote system teleoperation is stable under remote supervisory commands.

The interaction between both surgeons (local and remote), is provided through the endoscopic video image. The remote operator receives the laparoscopic image in the workstation, where the user interface allows an overlaid graphical annotation system. These marks are sent back to the operating room, where the local surgeon can see them on the standard laparoscopic video monitor. Also, a video-conference channel is available for a more natural communication.

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. However, the remote user (experienced/mentor surgeon) can control the arm in to ways: by sending the same commands than the local surgeon (‘Left’, ‘Right’, ‘Up’...); or by clicking on the endoscopic image. In this case, the robot moves the camera in order to centre the image on the selected point.

The remote user interface is intended to be the link between the operating room and a remote surgeon, who should be able to work from the wider possible range of locations. Thus, the workstation has been implemented on a standard PC computer. The mouse input device gave the best results due to its easy of use and integration with the operating systems’s GUI. Thus, 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.

The Operating Room side has been implemented by using a standard computer system. This sub-module provides the connectivity between the operating room and the rest of the world, managing the communications through a standard TCP/IP connection, as well as overlaying the graphical information from the remote user if the Extended Capabilities Module is not present.

OPERATING ROOM EXPERIENCE AND CONCLUSIONS

The project is currently undergoing the certification stage by the Spanish Health Authorities. An additional advantage of the modular configuration of the system is the possibility of facing this certification separately, so each module follows its own procedure. Thus, the Wireless Laparoscopic Robot, the first module, is completing the last preliminary steps before human experiments.

As a part of a previous stage, before the clinical trials on humans, several experiments on animals have been carried out. These were performed in local mode, that is, without using the other two modules of the system. Up to date, several operations on experimentation animals have been carried out including cholecistectomies, Nissen funduplicatures and anastomosis. During these trials (Fig. 2) the involved surgeons expressed their satisfaction about the system performances. Despite they received no training about the speech recognition interface, more than 90% out of the commands were succesfully recognized. As for the laparoscope movements, it has to be said that it fulfilled the expectations.

REFERENCES

[1] Cuschieri, A., and A. Melzer, “The impact of technologies in minimally invasive therapy”, *Surgical Endoscopy,* pp. 91-92. 1997.

[2] Fernández-Lozano J.J., *Robots para movimiento de la cámara en cirugía laparoscópica*. Phd. Thesis. Universidad de Málaga, Spain. 2002.

[3] Gómez de Gabriel J. *Contribuciones a la teleoperación con retardos de comunicación*. Phd. Thesis. Universidad de Málaga, Spain. 1999.

[4] Green P.S., J.W. Hill, J.F. Jenen and A. Shah, “Telepresence Surgery”, *IEEE Engineering In Medicine and Biology*, May/June 1995.

[5] Guthart, G.S. and J.K. Salisbury Jr. “The Intuitive™ telesurgery system: overview and application”, *Proceedings of the IEEE International Conference on Robotics and Automation, 2000*. Volume: 1. pp. 618 -621. San Francisco, USA, 2000.

[6] Muñoz V. F., C. Vara-Thorbeck, J. G. DeGabriel, J. F. Lozano, E. Sanchez-Badajoz, A. García-Cerezo, R. Toscano and A. Jiménez-Garrido. “A Medical Robotic Assistant For Minimally Invasive Surgery”, *Proceedings of the IEEE International Conference on Robotics and Automation, 2000*. Pages 2901-2906. San Francisco, USA. 2000.

[7] Satava R. M. *Cybersurgery: Advanced Technologies for Surgical Practice.* Wiley-Liss. ISBN 0-471-15874-7. New York, USA. 1998.