ROBOmed 94

1st European Conference on Medical Robotics

June, 20-22, 1994
Barcelona, SPAIN.

asociación
española
de robótica

UPC

ROBOTICS IN TELEMEDICINE

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ABSTRACT

The advance in endoscopic surgery with its related problems, the difficulties of instrument's control while increasing their degrees of freedom and the caracteristics of this kind of surgery (video assisted in absence of direct tissue manipulation) are on the ground of the researches in the application of telerobotics in endoscopic surgery which are carried on in several centres worldwide. From 1992 and 1993, three experiments have been carried out by the Laboratory of Telerobotics of the Politechnic of Milan and the 4th Department of Surgery of the University of Rome. During these experiments, remote controlled surgical acts have been executed through a master-slave robot system, either via a modem or a satellite link and the delay of signal transmission analised. The last experiment was conducted in cooperation with the Jet Propulsion Laboratory of NASA in Pasadena.

KEY WORDS: Telerobotics, Minimal Invasive Surgery, Endoscopic Surgery, Remote Manipulation, Transmission Delay, Animal Model, Interventional UltraSonography

1. - INTRODUCTION

Endoscopic Surgery has already changed in some way the behavior of surgeons in the operating room: they perform operations with the operating field farer than in conventional surgery; there is no direct view of the operating field, but surgeons operate watching the target tissue through a monitor connected with the camera assembled with the scope.

The limits of endoscopic surgery (loss of depth perception, restrained mouvements inside the body cavities) pushed several researchers to study and develop manipulators and robotic systems suitable for application in endoscopic procedures. In 1992 we started to investigate one of the main problems during remote controlled operations: the delay of signal transmission, which practically means the delay of execution of a remote transmitted surgical act. Several experiments, either via cable and satellite, have been carried out between Milan and Rome, Milan and Vimercate, and between Pasadena (California, USA) and Milan (in collaboration with the JPL-Jet Propulsion Laboratory of NASA) until July '93 to prove feasibility of transmission of basic surgical acts.

2. - MATERIAL AND METHODS

The first experiment, performed in December 1992, consisted in the computer controlled transmission of a surgical act (skin incision on a specially assembled dummy) between Milan (Politechnic) and Rome (Umberto I University Hospital), with a distance between the master and the slave station of 600 Km. The images of the operating field in Rome were transmitted to Milan and the robot commands were sent from Milan to Rome through numerical data transmission lines.

During the second experiment (between Politechnic of Milan and IBM of Vimercate) the transmission delay of surgical acts executed through a master-slave robot system (IBM SCARA) via a satellite link has been evaluated.

During the last experiment a Master/Slave robot IBM SCARA controlled by a dedicated software has been used; the surgical manoeuvres, executed by the surgeon in Pasadena, through a double satellite link, on a specially assembled dummy at Politechnic of Milan, containing a liver with an artificial cyst and coated with a "sylicon sheat", consisted in two incisions of its artificial coat at suitable sites for insertion of laparoscopic cannulae and optic, and an ultrasound guided puncture and aspiration of the liver cyst. The distance between the two centres was 14,000 Km and the overall back and forth distance runned by the signal was 300,000 Km.

2.1. - Electronic, Mecanic and Surgical Hardware

2.1.1. - Command Site

1. Personal Computers 486 DX, VGA graphics and Video Blaster 2 facilities
2. Modem
3. Terminal adapter ISDN
4. Monitors
5. Control device (mouse)

2.1.2. - Operative Site

1. Personal Computer 486 DX, VGA graphics and Video Blaster 2 facilities
2. Modem
3. Terminal adapter ISDN
4. Monitors
5. Solid state cameras (Sony) with software controlled zoom
6. Robot IBM SCARA 7565, with 4 DOF and AML2 working language
7. Aspiration needle with special connection for the robotic arm and dynamic sensor of applied forces with a precision of 0.1 gr.
8. 5 MHz ultra sound (US) convex probe (Aloka) with special connection for the robotic arm and US equipment by Aloka Company
9. Lancet with special connection for the robotic arm
10. Equipment for endoscopic surgery with digital video system and 3 ccd microcamera provided by Storz Company
11. Specially assembled dummies (i.e. anatomical model in the first experiment or animal model in the second experiment)

2.2. - Experiments Description

2.2.1. - First Experiment

Communication Start Up - The communication between the Rome and the Milan sites was set up by means of the two data transmission lines. A 2 Mbit/s line was used to send the images of the Rome site to Milan and a 9600 baud bidirectional numerical data transmission line provided the communication between the computers.

Robot Positioning - The Milan surgeon chose the robot position on the specially assembled dummy (anatomical model) through the images received from Rome and executes the commands for the robot positioning in the 3D spaace. The Milan site was monitoring the performance of each single phase of the sequence.

Task Execution - The Milan surgeon commanded the execution of a 1 cm cut on the surface of the dummy, required in laparoscopic surgery for the introduction of trocars.

2.2.2. - Second Experiment

Several tests between the Politechnic of Milan and the IBM laboratories in Vimercate have been performed to evaluate the delay of signal transmission during remote controlled surgical acts through a master-slave robot system with satellite link (geoid satellite, 36,000 Km height orbit). The back and forth transmission time has been analised.

2.2.3. - Third Experiment

Communication Start Up - The communication between Pasadena (JPL - NASA) and Milan (Politechnic) was set up by means of two bidirectional numerical data transmission lines and a double satellite (geoid orbit at 40,000 km height) link provided by STET, ITALCABLE, TELESPAZIO, SIP, NASA, AT&T and SPRINTER.

Robot Positioning - The surgeon in Pasadena chose the robot position on the specially assembled dummy (animal model) through the images received from Milan and executed the commands for the positioning of the robot in the 3D space.

Task Execution - The surgeon in Pasadena commanded the execution of the US scanning of the liver in the animal like dummy (containing swine liver). After targeting the cyst artificially created in the liver the surgeon commanded the puncture of the cyst itself which was thereafter aspirated manually. Afterwards the surgeon commanded the execution of two (10 mm and 5 mm long) cuts on the coating surface of the dummy, which are required for trocar insertion in laparoscopic surgery. The second cut was monitorized by a two camera system (external camera and endo -3 ccd-camera).

3. - RESULTS

3.1. - FIRST EXPERIMENT

The experiment succeeded. In this experiment, the data and video transmission from the remote surgeon to the operating room was affected by a time delay of 0.5 s.

3.2. - SECOND EXPERIMENT

The signal trasmission delay between the master-computer and the slave-robot with satellite connection was evaluated to be 1.1 s back and 1.1 s forth.

3.3. - THIRD EXPERIMENT

Two tests have been seccessfully performed. The transmission of the surgical acts was affected by an overall time delay of 2.2 s (1.1 back and 1.1 forth) mainly due to the signal passage through the surface link stations.

4. - DISCUSSION

This initial experience was meant to demonstrate that consistent results may be obtained by telerobotic surgery. Teleoperation techniques allow the surgeon to communicate and operate in different sites. Moreover, a proper apparatus allows the performance of

basic surgical manouvres in extreme situations such as deep space missions, contaminated areas, war fields.
The experiments showed the still existing limits of telerobotic surgery, mainly consisting in the robotic hardware (i.e. limited DOF) and in the transmission delay.
The real conditions during surgery are still extremely distant from their representation by simulation with static anatomical models. In fact, there were no dynamic changes of the operative field during the experiments and this is far different from the operative view of an alive model.
These two factors, delay of signal transmission and dynamic changes of the operative field, mean that safety measures and feed-back functions are required during telerobotic manipulation.
The research in this field will carry a number of side developments which will be brought into the daily surgical practice (i.e. sensorized systems for instruments positioning, 3D imaging, surgical manipulators) and is the first step toward virtual reality in surgery.
Virtual reality will be the logically consequent evolution and will carry a dramatic change in surgical training. Interactive training on dynamic 3D simulators with sensorized instruments will allow to avoid the learning curve of the surgeons and operations on animals durin training courses.
The last point is the human-machine interaction, in term of reaction time during telesurgical procedures and psycological implications.
We are just at the beginning of the research in this field but the initial results are promising and the interest that the scientific community has shown and the number of joint projects and programs which have been started (CNR, ARPA, EUREKA MASTER) witness that we are running the right way.