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A Sensorized Minimally Invasive Surgery Tool for Detecting Tissutal Elastic Properties

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Abstract

Nowadays, the surgeon who is using minimally invasive tools looses almost completely the haptic perception of the manipulated tissue. In particular, he or she looses the perception of the tissue elastic properties. It is possible to modify actual mini-invasive surgical tools in such a way they may give a reliable estimation of the manipulated tissue properties for recognition and characterization purpose. Here we present a first attempt to realize a prototype of sensorized surgical tool by modification of a commercial tool. Experimental tests have shown that using such a tool could enhance surgeon's haptic perception of the manipulated tissue.

1 Introduction

Minimally invasive surgery is a technique developed to reduce the traumatic effect of some surgical operation; it has had a great development in the last years. For example, the first laparoscopic cholecystectomy (gall bladder removal) was made by P. Moruet at Lyon in 1987; in 1992, 70 percent of all gall bladder surgery in U.S., Europe, and Japan was done laparoscopically [1] and, at now, 500 000 operations are made in a year in the USA. The reasons of such a fast increase are known: reduction of risks, disfigurement, and patient pain; shorter immobilization (about 24 hours for cholecystectomy); shorter hospitalization (about 2-24 hours), and an earlier return at work (about 7 days). These advantages may be translated into a total health care cost reduction for commercial and governmental institutions as well as for the patient [3]. Minimally invasive surgery is now used in laparoscopic biliary tract surgery, appendectomy, and gynecology, in thoracoscopic treatment of pulmonary problem (diagnoses, drainage, and surgical treatment), arthroscopic examination and care, and neurosurgery.

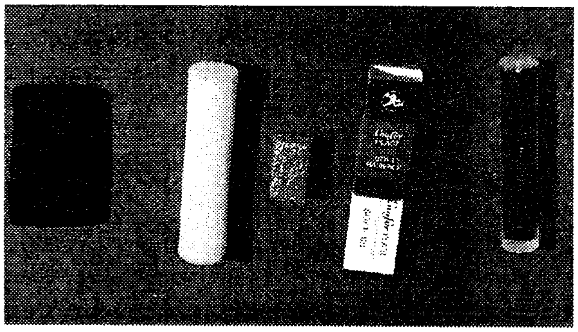

Figure 1: A photography of the object used in the blind test in a stiffness order: (from left to right) three different kind of sponge, an eraser and a Plexiglass^{TM} cylindrical.

In minimally invasive surgery the rôle of advanced technology is perhaps more important than in other field. In a laparoscopic operation, the surgeon operates through small openings (between 3 and 12 mm) in the abdominal wall of the patient. An inert gas (usually CO_2) is introduced to distend the peritoneal cavity. One of the openings is used to introduce a miniature camera (including a cold light source). Camera images are shown on a monitor; the camera is manipulated by an expert operator. The head physician and his assistants operate using a set of elongated slim rigid tools provided of an appropriate utensil on the tip. The tip is manipulated using the handle of the tools. The transmission of force and motion from the handle to the tip is actuated by means of levers.

There still are many problems related to the use of this technique; for example, an important effort is devoted to the research and the design of new tools for complex purpose, such as suture or pinching. More-

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over, robotics assistance as a "robotic camera operator" and "robotic tools operator" have been proposed [4,8–10]; it is actually possible to integrate some medical images analysis with the planning and the execution of mini-invasive operation; other researchers are investigating on the possibilities of enhancing the surgeon sensibility in both manipulating and sensing tissue properties [7] while other are investigating on teleoperation and telepresence laparoscopic surgery (in particular for military application) [5,6]; finally, an important attention is posed in surgeon training for mini-invasive operation, using virtual reality and telepresence tools [2]. Research in new surgical or training techniques should keep into account the human factor, namely their acceptability to the surgeon staff. Zucker *et al.* [11] resume the problem with the phrase: "general surgery, however, is a conservative discipline, an attribute that once served is well. General surgeons also tend to trust their visual and tactile senses more than *technology*".

2 Problem Description

The literature and the direct interview of specialized surgeons pointed out that minimally invasive surgery is still afflicted with important limits. The most important one is the surgeon loosing of both tactile and kinesthetic sensibility due to friction and backlash present in the transmission mechanism of the elongated tools. The surgeon may manipulate patient's viscera only using long tools, observing actions and movements on a monitor visualizing abdominal environment. He can not either touch or see viscera directly and that restricts the application of this technique only to some specific fields (like those cited in the introduction). Diminished tactile sensibility causes a loss of surgeon's palpation evaluation capability, in particular with regard to tissue's compliance and viscosity. These effects are so important that it become very difficult to discriminate the anatomical nature of the manipulated tissue. This is true, in particular, if the camera images are not sufficient or absent. In such cases, losses on perception may cause important lesions.

To get an exact perception of the operating environment and of surgeon action and movement we were present at a laparoscopic operation. We also assisted to a traumatic event on the gall bladder due to the losses of perception of the surgeon assistant. Such an event is rare, particularly on vital viscus (gall bladder had to be removed): anyway, a better sensibility may diminish the incidence these events and optimize grasping force during manipulation.

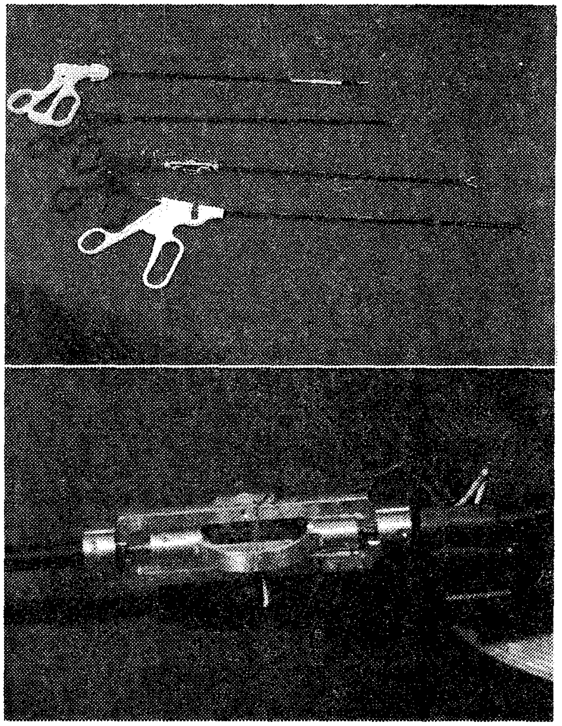

Figure 2: **Up** A photography of normal laparoscopic tools (pliers, scissors *etc.*); **down** a photography of our prototype of sensorized laparoscopic tool.

To investigate on the tactile sensibility drop, we performed two preliminary ***blind tests.*** The first one consisted in the manual training of six subjects on recognition of five objects made of different material (see Figure 1). The subjects had enough time to manipulate the objets. After this preliminary phase we gave them a commercial laparoscopic tool (see Figure 2 up) with which they manipulate, one by one, the objects in Figure 1 casually selected. Subjects had to try to recognize the objects without seeing them. The result was eloquent: the recognition rate was as low as 30 % in mean. Second test consisted on performing the training phase manipulating the object by means of the tools. In this case the recognition rate raises to 50 %. We used objects materials with different characteristics: from about that of bone to that of hepatic tissue. These blind tests are not statistically meaningful but confirm the surgeon observation about loss of sensations.

Our solution to the problem we just described, consists in the realization of a sensorial module for some mini-tools which have the greatest need of an enhanced sensibility. Our module is able to measure the force really applied from the tools to the tissue and the angular displacement of the tools jaws. Using these signals it is possible to monitor the applied force and to extract some of the viscoelastic characteristics of the manipulated tissue.

3 The minimally invasive surgical tool

3.1 The hardware structure

The goal of the work was to realize a sensorized prototype of laparoscopic tool able to realize real time data acquisition and analysis. The first phase of the work was to choose the best strategy for the prototype realization. We decided to modify a commercial tool, working on tools real dimensions and with the actual problem of friction and backlash. The lower part of Figure 2 shows the prototype of the tool with the sensors module. The commercial tool, laparoscopic pliers, has a very simple mechanical structure: a rigid beam (RB) is actuated by the handle. Its forward-backward movement closes and opens the jaws.

The best position for the sensors is as near as possible to the jaws. In this case measured force is not affected by friction and by backlash. Anyway this was only a preliminary work and we decided to insert our sensors near the handle, to respect the simplicity of original mechanism. The purpose was also to study the acquisition electronic and evaluate the tool recognition capability of tissue properties.

The sensors module needs to be able to measure the applied force and the jaws position. Figure 3 depicts the sensor module without the covering; it shows the two sensors:

- the force sensor is realized applying two strain-gauges to an aluminum ring: the ring deformation causes gauge resistance variation. Using two strain-gauges on the same half of a Wheatstone bridge allows good temperature compensation. The sensor measurement is affected by friction.
- The position sensor is realized using an optical position sensing device (PSD). It is a semiconductor optical device on which a light emitting diode (LED) is placed. Light injection causes the generation of two corrents: the difference of these corrents is a linear function of the LED position above the PSD. The LED is integral with RB and its position is an indirect measure of the jaws angles. This measure is, obviously, affected by backlash.

Strain-gauges Wheatstone-bridge unbalance is detected by means of an instrumental amplifier. PSD corrents are amplified using two corrents amplifiers.

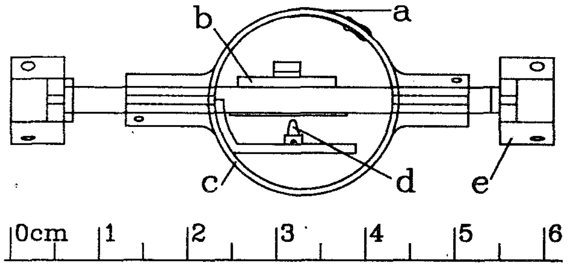

Figure 3: A drawing of the sensors inside the module: the ring **c** is fixed to RB; Strain gauges **a** are fixed on opposite side of the ring, in such a way to act in complementary way; LED **d** is fixed to the ring by means of a small fixture; the ring follow the RB movement and the light spot change position on the PSD **b**; PSD is integral with the structure **e** which join the two pieces of the tool: the handler and the utensil part.

Finally the three signals are connected to the analog inputs of a microcontroller using three amplifiers: they adapt and filter sensors signals.

To acquire sensors signals we used a TMS370C756 (from Texas Instruments), an 8 bit microcontroller with 8 Analog to Digital inputs, an asynchronous and a synchronous serial port, 3 8 bit input-output digital ports. This microcontroller has very good characteristics and we only used it partially.

We programmed the microcontroller to acquire sensors signals and to send them to a PC by means of the asynchronous serial port. The complete circuit is realized on two double-metal-layer 8 × 8 cm custom printed circuit boards. The two boards can be stacked together to obtain a compact structure.

3.2 The software structure

The platform able to analyze the sensor signal is a normal PC with an available serial port. Data are shown using a graphic user interface (GUI) realized using Visual C$^{\copyright}$ (see Figure 4). To give information about the manipulation by means of a graphical interface is not a major disadvantage considering that, while doing a laparoscopic operation, surgeons need to look at a monitor on or near which it is possible to add force and displacement display.

To allow data analysis and acquisition while other programs are running we realized a data transfer mechanism based on program interruption. Data are graphically shown using an analog or a digital display (display type is optional) for both force, angular displacement and the most important compliance pa-

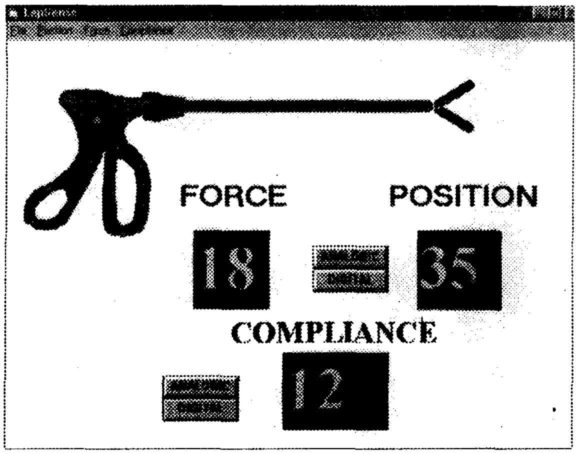

Figure 4: A picture of the window used to show the information to the surgeon. A digital display is shown for all the information. The angle of the pliers of the tools may change following the real tools.

rameter (see next section). Another option permits to perform a test of the manipulated tissue producing a graphical output (see next section).

4 Experimental results

4.1 Sensor test and calibration

Before to acquire data it has been necessary to calibrate and to characterize sensors. We calibrated the linearity of our force sensor using a load cell. The output of the sensor is perfectly linear in the operative field and does not depend on temperature variation (from 30 to 50°C). Position sensor was calibrated using a drawing with calibrated angles. This sensor also has a linear behavior and does not depend on temperature variation

After calibration of the tool we ran our acquisition program. The GUI showed, real time, the sensor output allowing to know the applied force and the openings of the jaws.

4.2 Blind test using the prototype

Using an option of our program, we also realized a third blind test with the sensorized tool. Figure 5 show the results of our experiment, consisting in a quasi-static force-deformation test. The angular position variation is shown on the x-axis and the applied force on the y-axis. From Figure 5 is possible to elicit that material discrimination is, in this case, easier than in the other blind tests.

An experiment with the same subject of the other tests gave a recognition rate of 95%: a small amount of error is due to the fact that material **a**, **b**, and **c** have very similar force-displacement characteristics.

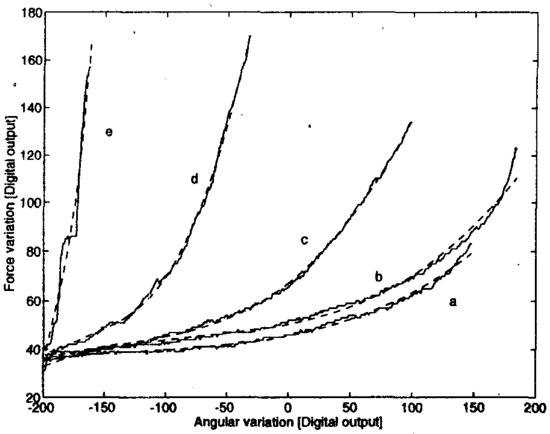

Figure 5: Result of the third blind test: curves **a** to **e** are obtained manipulating the objects in Figure 1 from left to right. Data fitting produced using a third order polynomial interpolation is also shown (coefficients obtained from this interpolation are shown in Table 1).

4.3 Model description and data analysis

Static curves on Figure 5 clearly show that a linear model is not applicable to fit these data. We fitted them using a third order polynomial interpolation. To model this data behavior is possible to use a viscoelastic non-linear concentrated parameter model. We still have not try to develop such a model.

In Table 1 we report the three higher order parameters of the polynomial interpolation of curves in Figure 5 (order zero parameter depends on the grasping initial condition). Table 1 also shows the result of a recognition trial. For our objects recognition, the third order coefficient comparison seems give optimal results and it is shown from the program during objects manipulation.

5 Discussion and conclusions

The purpose of this work was to solve, or partially compensate, problems due to surgeon losses of sensibility during minimally invasive operation. We modified a commercial laparoscopic tool applying a sensorial module able to measure the force really applied from the tool and the angular displacement of the tool jaws. The applied sensors are small, reliable, and do not change the functionality of the tool; signal conditioning is performed using a reliable technology. Using

sample	coef. 1	coef. 2	coef. 3
a	0.0001	0.1004	45.5712
a'	0.0005	0.0810	44.4263
b	0.0007	0.1016	50.3605
b'	0.0005	0.1125	50.4423
c	0.0023	0.3946	67.2098
c'	0.0018	0.4340	68.1356
d	0.0217	3.7370	270.676
d'	0.0123	2.7087	240.8675
e	1.2482	239.67	15530.3
e'	0.9987	220.98	14388.3

Table 1: Table with parameters identified using polynomial fitting. **a** to **e** are reference tests on the five objects of Figure 1 from left to right; **a'** to **e'** are recognition test on the same five objects.

sensors signals we monitored the applied force and we extracted some of the viscoelastic characteristics of the manipulated tissue.

The simple graphic of force versus angular displacement easily permits to identify different test objects. A parametric identification of the acquired data was also performed: different objects are recognizable by means of the identified parameters.

Two blind tests confirmed the real loss of sensation due to manipulation by means of long tools; a third blind test, realized using our sensorized tool, demonstrated that the five objects may be recognized without errors. Only very similar material may cause some confusion.

We are now working in three different directions to continue this study. A direction consists in the realization of a "tactile display", useful to give, in a simple form, information about the tissue consistence to the surgeon. Howe *et al.* [7] are working on a similar project: a palpation system (sensor and haptic display) for laparoscopic surgery. Another research consists in the design and realization of a sensorized and actuated tool with a full compensation of friction and backlash. This advanced tools should restore the surgeon kinesthetic perception without alienating the direct control of the jaws from the surgeon. We also noted, following a real operation, that surgeon's movements are quite slow: this fact makes easier the realization of working actuated tools. The last research line consists in the realization of a sensorized tool in which the sensor are as near to the jaws as possible. Only this configuration will permit a good compensation of friction and backlash.

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