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A New Robotic Platform for Endoscopic Skill Training

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ABSTRACT

Background: Applications of Minimally Invasive Surgery (MIS) techniques are quickly extending.

Therefore, also surgical education is changing rapidly, although several factors, including budget constraints and medico-legal concerns, still limit opportunities for pediatric trainees. New training devices, such as low fidelity bench trainers and virtual reality simulators, offer new ways for surgical training. Moreover, there is considerable interest in the development of haptic simulators for MIS even though the importance of force feedback remains poorly understood.

Methods: In this report, we present the LapLab (Laparoscopic Laboratory) device, an innovative laparoscopic training solution developed at the University of Bologna.

Results: LapLab is a haptic simulator for MIS designed to improve and test the skill of surgeons. Moreover, it also allows to test in safe conditions (i.e. by means of realistic simulations) new kinds of MIS instruments.

Conclusions:Actually the LapLab simulation system has matured from a technological point of view, but still it represents just a starting point for a new generation of simulation systems able to give a real contribute to the education and training of the surgeons of tomorrow.

Introduction

Figure 1 – a) Trainer Box; b) Virtual Reality Simulator (LapSim).

Nowadays, basic training in laparoscopy is executed in three ways: Trainings Based on real Animals (TBA), Laparoscopic Trainer Box (LTB) (Fig.1a), and Virtual Reality Simulators (VRS) (Fig.1b). The training on living animals represents the best solution in terms of force feedback and realism, but on the other hand it is very expensive and involves several ethical concerns. The LTB is typically used to perform basic tasks aiming at improving the movement coordination. Force feedback is present, but they are quite expensive because the anatomical models used are perishable.

VRS represents a good compromise between the LTB and TBA, allowing the user to perform several different exercises and dissection tasks, just selecting the desired program. Another advantage provided by VRS is the repeatability of every task during different school terms. As a matter of fact, repeatability is an important feature of VRS because it allows more users to perform the same task (possibly on different computers, in different locations and in different times) and compare their results and performances in a clear and deterministic manner.

Another important aspect of VRS is the possibility to follow a structured work plan or a didactic program defined for different profiles of users. For example, it is possible to assign a set of basic tasks for a novice student (for improving the movement coordination), or a set of rare/complex intervention operations for a senior surgeon in order to maintain a constant ability to perform specific operations **[1-8]**. Unfortunately, VRS has an important limitation, i.e. the absence of force feedback (or haptic rendering). The majority of the simulators cannot offer haptic rendering, a very important feature that allows perceiving a (simulated) contact with the tissues, therefore improving the movement coordination of the surgeons. In some commercial simulators (i.e. LapSim**[9]**), force feedback is optional. Only few simulators are equipped with robotic devices that allow force feedback **[10]**. Usually, the generated forces are not coherent with the reality and, moreover, they are directed only along directions perpendicular to the simulated objects, whereas in tangential directions it is not possible to feel anything. LapLab (Laparoscopic Laboratory), the system described in this paper, allows a whole haptic rendering. The effects generated from the simulation software are computed along the foundation of mechanical-elastic parameters derived from real tissue analysis. These features allow a quite realistic simulation of a real surgical operation.

Materials and methods

The LapLab

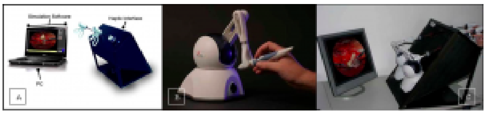

Figure 2 – a) Basic components of LapLab; b) PHANTOM Omni by SensAble; c) Haptic devices connected to a couple of laparoscopic tools.

The system is composed of two main components: a personal computer, running the simulation of the surgical operations with the related procedures (e.g. the storage and analysis of the results, on-line help, the computation of the interaction forces,…) and the haptic display of force rendering of the user (Fig.2a).

The simulation software may run also on a middle/low cost computer platform equipped with Microsoft Windows XP or Vista Operating System (reference configuration: 2Ghz CPU, 1-2 Gbyte of RAM, an Nvidia GeForce 7800GTX graphic board, 80 Gbyte hard disk).

A couple of SensAble PHANTOM Omni devices are currently used as haptic interfaces. A haptic device, as the PHANTOM Omni, is a particular robot that may apply a desired force (direction and intensity) on the stylus connected at its end, (Fig.2b).

In particular, the PHANTOM Omni is a low-cost haptic device available on the market, capable to generate an acceptable quality of haptic rendering. Although it stands for a serious tool for haptic rendering, the PHANTOM stylus is obviously different from a laparoscopic device. For this reason, the original stylus of the PHANTOMs has been replaced by surgical tools. Moreover, the two devices have been introduced into an appropriate case (Fig.2c), to simulate a typical surgical configuration.

Although their behavior is quite acceptable, the PHANTOMs devices adopted for the current system represents merely an initial result, being the final end to get an ad hoc haptic device optimized for this sort of applications. Note that, although the simulation of the surgical operations is quite satisfactory both from the graphical and force feedback point of views, the overall hardware configuration is very cheap: more or less 6.000 USD, of which about 4.000 USD for the two PHANTOMs.

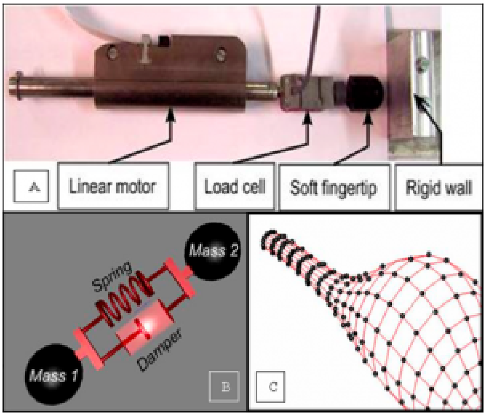

Figure 3 – a) Mechanic-elasticity tester; b) Mass-Spring-Damper model; c) A FEM tissue model.

The mechanic-elastic parameters of the tissues can be estimated by means of off-line experimental tests. For this use, a specific apparatus must be planned and made. The device should be based on an electric motor connected to a load cell (used for force measurement) and controlled by a computer. The motor is utilized to apply different, controlled forces on real tissue samples (derived from animals), (Fig.3a) **[11]**.

The status and force measurements obtained with this sort of device during interaction with a specific material can then be utilized for the mathematical modelling of synthetic tissues used for the surgical simulation. In order to improve the feedback quality, we are planning to develop new methodologies and instruments, to be used possibly with standard laparoscopic tools that should be used in real time during normal operations.

The Simulation Software

The simulation software is entirely developed in Microsoft Visual C++, and is subdivided into two main parts.

The first part is the management program that allows the system administrator to manage all the user profiles and the simulation libraries. The second block is the simulation library (SIML). SIML is a set of different simulations and exercises implemented in separate modules in order to decrease the overall complexity. The simulations are based on the same graphics engine and on an *ad-hoc* physical engine (PE) optimized for elastic tissue representation. On the basis of the experimental activity for the deduction of the physical parameters of real tissues, the PE is able to simulate all the different materials involved in the simulation. The virtual tissues are modelled with a FEM (*Finite Element Model*) model **[12,13,14]**, i.e. a complex grid composed of several particles (masses) connected by springs and dampers, (Fig.3b). In this model, there are four different parameters characterizing the material: the mass of the particles, the stiffness of the springs, the viscosity of the dampers, and the density of particles for each unit of volume, (Fig.3c). With a proper choice of these four parameters, it is possible to simulate the behavior of several different materials. The computational burden for the simulation of FEM models for each frame of the surgical operations is relevant. Therefore, the simulation algorithm has been suitably optimized for this type of application **[15,16]**.

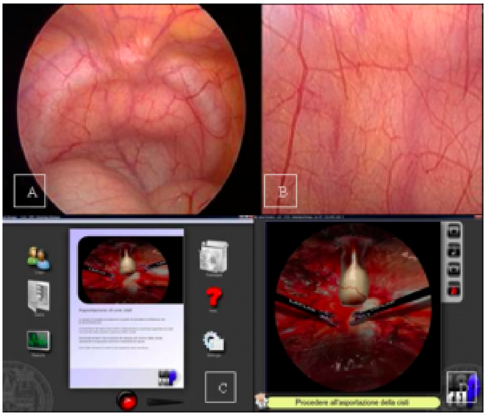

Figure 4 – a) Original image; b) the texture of original image; c) LapLab Management user interface; d) LapLab sample simulation user interface

Besides their physical properties, for realistic (graphical) simulations of the tissues it is necessary to have also their textures, i.e. a set of pictures derived from the real tissues, (Fig.4a e 4b). As a matter of fact, just applying the texture set, it is possible to plan a realistic surgical scenario.

An important component of the simulation software is the Virtual Tutor, a software module based on an artificial intelligence algorithm. The Virtual Tutor takes care of two significant tasks. The first one is to assist users in correctly performing the surgical task, suggesting the best sequence of operations to be carried out. The second one is to evaluate the performances of different user by measuring objective parameters giving the quality of the operation, i.e. movement coordination, errors, and so on. Figures 4c and 4d show three different screenshots of the simulation software.

Discussion and Conclusions

New laparoscopic simulation systems, based on haptic robotic interfaces allowing the function of force feedback devices in VRS, create a more realistic field of operations in which novice surgeons can learn functional skills. Surgical simulation is an exciting field of surgical training. The future is bright as advancements in computing and graphical capabilities will offer new innovations in simulator technology. Simulators must continue to undergo rigorous validation studies to assure that time spent by trainees on bench trainers and virtual reality simulators will translate into improved surgical skills in the operating room. Actually the LapLab simulation system has grown from a technical point of view, but nonetheless it represents only a beginning point for a young generation of simulation systems able to apply a real contribute to the teaching and preparation of the surgeons of tomorrow.

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