Accurate and Low Cost Training System for Robotic Surgery

Davide Zerbato, Luca Vezzaro, Lorenzo Grespan, Lorenza Gasperotti and Paolo Fiorini
Department of Computer Science
University of Verona
Verona, Italy
Email: davide.zerbato@univr.it

***Abstract*—Surgeons' training is mainly based on a Halstedian apprenticeship model whereby residents learn by directly assisting an experienced surgeon during the intervention and slowly increase their hands-on experience over time. Hands on training is indeed essential for effective training to robotic surgery, however the reservation of the robot for training represents an additional cost that hospitals can hardly afford . A possible solution to this problem is the use of simulators.**

Current surgical simulators have some severe limitations in the realism of the physics simulation provided and this reduces their effectiveness. Improving the realism of physics simulation is thus one of the ways to further increase cos/benefits ratio of simulators.

This paper describes Chiron, a new simulator for robotic surgery which is focused on providing realistic simulations and thus to increase the training outcome. The simulator currently provides more than twenty tasks, some are inspired by the tasks used in current training curricula whereas other have been developed to exploit the specific functionalities of the software and to evaluate users cognitive load. Thanks to the scripting language integrated into the software, it is possible to easily customize all the tasks and to quickly develop new ones following the requirements of several surgery specialization.

The simulator is currently being validated in different hospitals and training centers in Europe and USA.

I. Introduction

Surgeons training is mainly based on a Halstedian apprenticeship model [1] whereby residents learn by directly assisting an experienced surgeon during the intervention and slowly increase their hands-on experience over time. This approach is difficult to extend to robotic surgery, where only the surgeon (or at most one other person) can actually control the robot and have the stereoscopic view of the intervention area whereas assistants can only have an overall impression of the procedure flow. Hands on training is essential for effective training to robotic surgery, however the reservation of the robot for training represents an additional cost that hospitals can hardly afford [2].

A suitable solution to this problem is the use of simulations. Virtual simulations, in particular, are suited since in robotic surgery the surgeon interacts with the robot console, composed by haptic devices and monitors, which can be easily replicated with lower cost devices. Simulations should reproduce two important aspects of the intervention: the robot, with its kinematics and dynamics properties, and the patient, with anatomy, pathology and, possibly, physiology [3]. The reconstruction and the simulation of complex anatomical scenarios is still an open problem, both from the point of view of modeling but also for computation. Thus virtual simulations often focus on the development of basic skills [4] , which do not require high anatomical realism to be trained as they are more related to the dexterous use of the robot. Virtual simulators demonstrated to effectively support the acquisition of the basic skills required by minimally invasive surgery in a safer, less stressing and cheaper way. Real time data recording constitutes a relevant advantage provided by these tools and makes their application in training and evaluation extremely valuable and effective [5]. However, basic abilities only enable the surgeon to dexterously control the robot but they do not ensure that he/she can carry out a surgical procedure following the right steps, without harming the patient and effectively facing adverse events.

Fig. 1. Examples of hardware configuration supported by the training system: in foreground a pair of Sensable Phantom Omni plus Zeiss Cinemizer glasses providing 3D vision and in background one Razer Hydra and standard 2D monitor.

Surgical simulators available on the market [7], [6], [8] suffer from some severe limitations, such as objects intersection, extremely hard constraints between grabbed objects and robots. Moreover simulated surgical tools only reproduce the end part of the actual robot, without modeling the dynamics of the whole robot. These limitations reduce the usefulness of the simulation for procedural abilities. In fact, for a training tool to be effective, it is mandatory to ensure its realism both in terms of robot dexterity and physics realism. The absence of

physics realism in particular can lead the trainee to learn wrong maneuvers. If, for example, the interaction between a suture needle and the tissue being punctured is poorly modeled, the surgeon learns how to move the wrist of the robot, but cannot learn how to actually insert needles without damaging tissues. Another severe limitation of current simulators is their cost effectiveness. A single training station usually costs more than 60 thousand Euros, thus the cost of the training remains high even in presence of these simulators. Improving the realism of physics simulation is one of the ways to make simulators more useful to surgeons. This paper reports on Chiron, a system for robotic surgery training whose primary characteristic is the correctness of physics simulation.

II. Material and Methods

The goal of the work described in this paper is the development of a training system that ensures reduced costs and accuracy in the physics simulation. One of the requisites of the final system is the compatibility with different hardware configurations: this translates into the possibility to adapt it to existing hardware and to provide different levels of realism in the interface in accordance with user proficiency. In fact high realism may impede the learning process in novices because of the cognitive load.

On the software side, the training system must be based on free libraries, to ensure that the cost of the simulator is kept low. The developed simulation software is thus based on on the open source Bullet Physics library [9] and interfaces with many different hardware devices to provide input/output capabilities. The software has a modular architecture with four modules that handle: 1) physics, 2) graphics, 3) haptic devices and 4) logic.

The physics module is the core of the training system: it is in charge of the simulation of the physics phenomena (e.g. interactions between objects, friction, deformations, robot motion) and takes advantage of the functionalities provided by Bullet, i.e. collision detection, constraint solver, rigid body dynamics. The big limitation with Bullet is represented by its poor deformable models. As correctly modeling deformations is one of the key requirements to train surgeons to handle biological tissues and suture threads, Bullet has been extended with support to proprietary deformable models [10]. Thanks to this extension the training system is able to compute the internal strain due to deformations, which means that the simulation can handle tears and rupture of biologic tissues and thread but it can also keep track of the necrosis that is inflicted by user. This, in turns, results in more realistic training scenarios and in more complex and complete evaluation metrics.

The graphics module, instead, renders the interface and the scene to the user. The graphics module gets the description of the scene from the physics module and compute the graphics rendering, with the support for different kinds of stereoscopic visualization. This is required to reproduce the Da Vinci visual experience on different hardware configurations. The graphics module also handles the graphical user interface thus providing information and hints to the user during all the training curriculum.

The haptic module embeds all the routines that handle the input device and translate users movements into actions of the robot. This includes motion scaling, tremor filtering and the actual mapping of users motion into the frame of reference associated to the virtual endoscope. One key aspect of the haptic module is the support for different hardware configurations.

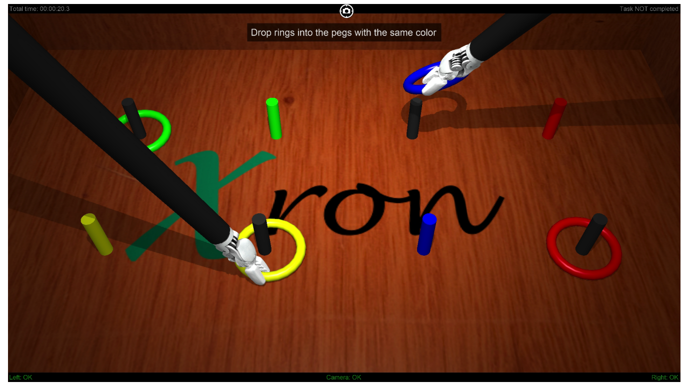

Fig. 2. One of the tasks currently supported by the simulator (Peg transfer) with step-by-step help message.

The last module of the training system is the logic module which is in charge of the logics of the training tasks. The training supervisor can, in fact, describe the task goals and the evolution of the environment by defining a finite state machine (FSM) that reacts to user inputs. In this way it is possible to keep track of user performance and errors in the execution of tasks and to generate hints to assist the surgeon during the training. The same scripting language that is used to define the FSM can be used online to customize many aspect of the training tasks or to insert adverse events in the simulation.

III. Results

The training system supports a wide range of hardware devices, thus providing scalable configurations and costs. The software runs on standard modern PCs with Windows 7 or 8 operating system. It supports many different input devices: from the low cost Hydra by Razer to Geomagic Touch, and from Omega by Force Dimension to Freedom 6/7s by MPB. When supported by the hardware device the system can also provide force feedback during the interaction with the virtual environment or to reproduce Da Vinci system behaviors. Thanks to its support to HDMI 1.4 3D rendering the software can take advantage of all the modern 3D monitors and head mounted displays to provide the same stereoscopic view that the surgeon experiences using the Da Vinci. However the simulator is also compatible with older hardware that use the side by side format to encode 3D rendering (see Figure 1).

Chiron currently provides more than twenty tasks, some are inspired by the tasks used in current training curricula (e.g. peg transfer, torn wire, bimanual pick and place - see Figure 2) whereas other have been developed from scratch to exploit the specific functionalities of the software and to evaluate users cognitive load (tasks inspired by Simon electronic game, tasks with random adverse events). It includes realistic anatomies and organs that can be obtained from CT or MRI segmentations with reduced efforts. This allows to reproduce specific anatomies or pathologies (see Figure 3).

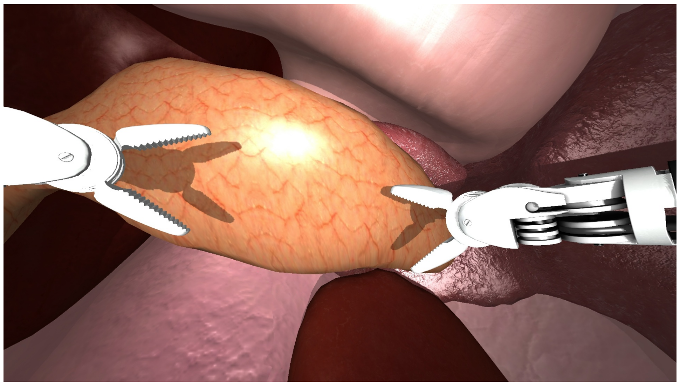

Fig. 3. Reconstruction of a pig abdomen with pancreas in foreground and stomach, liver, spleen and kidneys in background.

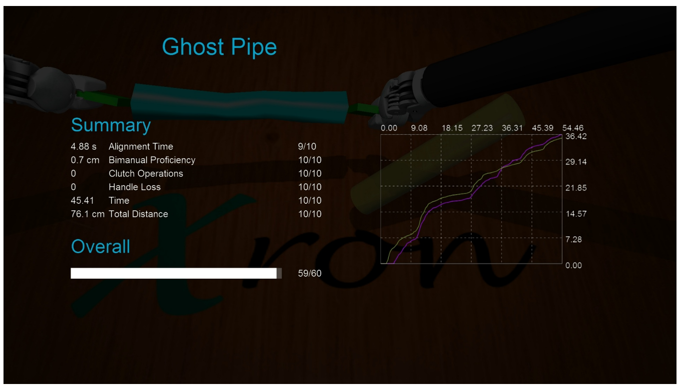

Fig. 4. Screenshot of the final score provided by the system. Along with the overall evaluation the user can understand where he/she can improve and has a graphical representation of the distance covered by each tool.

The scripting language integrated into the software allows to easily extend the training curriculum. In particular it supports the definition of the virtual environment, in terms of number, position and parameters of objects and organs in the scene. It allows determining the logic of the training task, through the design of the FSM that rules the evolution of the environment. Finally, it supports the definition of the metrics and the scoring system that evaluate trainee performances (Figure 4). This results in the possibility to quickly develop new tasks following the requirements of the target surgery specialization.

As a result of its flexibility, Chiron has been used in SAFROS European Project [11] in which it provided the virtual platform for an innovative training curriculum. In addition it is currently in use in several hospitals and training centers around Europe and USA. The validation of the system is ongoing[12]. The simulator is provided for free upon request to interested hospitals or institutions [13].

IV. Discussion and Future Work

The training system described in this paper combines the realism provided by physics engine and the flexibility of modular approach. In particular it features all the benefits of Bullet Physics plus the advantages of proprietary deformable models, and seamlessly interfaces with a number of input/output devices. It is currently being validated in different hospitals and training centers in EU and USA.

Using the same technology other training systems are currently under development, in particular, Chiron has been interfaced with two Simball 4D devices to obtain a laparoscopic surgery training system. A hysteroscopy simulator is also being developed.

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