# Development of a Serious Game for Laparoscopic Suture Training

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**Abstract.** Surgeon training in laparoscopic suturing is very important because this task generally requires an high level of experience from the surgeon. Serious gaming refers to a computer games technology where the primary goal is to train the player. In this kind of training the education goal is achieved also ensuring the entertainment and the engagement factors typical of a traditional game. This paper presents the development of a serious game for training on suturing in laparoscopic surgery that is focused on the physical modeling of the virtual environment and on the definition of a set of parameters used to assess the level of skills developed by the trainees.

**Keywords:** Serious game · Simulation · Surgical training · Laparoscopic suturing.

## 1 Introduction

The spreading of Minimally Invasive Surgery (MIS) reduced the trauma and surgical cut on patients. The use of this type of surgical technique has led to an increasing demand of education and training of surgeons. Furthermore traditional approach to learning and teaching based on the use of animals, cadavers or dummies appears obsolete.

As compared to traditional surgical techniques (i.e. open surgery), in MIS surgeons operate in a very small workspace, without having a direct view of the organs that are visualized by means of a camera. For this reason, in this context, some skills such as eye-hand coordination are fundamental for the success of the surgical operation. Surgeons need to have an accurate training with this type of technique.

The introduction of the simulation based on the Virtual Reality (VR) technology has completely changed the education and training tools and, since 1998, the virtual simulators are officially accepted as training tools for surgeons. Several studies have demonstrated how the virtual reality-based simulators, compared to training based on traditional methods, can significantly reduce the intra-operative errors [1].

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The VR-based simulators allow reproducing different surgical scenarios without risks for the patient. They have also the advantage of the repeatability of the training sessions in order to evaluate and study the mistakes. In addition, these simulators provide an objective measurement of the developed skills. It is also possible to reuse many times the simulator because the virtual environment does not undergo the degradation of the traditional toolbox used for training.

Nowadays VR-based laparoscopic simulators have achieved a high level of accuracy. The use of haptic devices able to provide a force feedback to the user has contributed to the spread of the virtual simulators developed for surgery training.

Laparoscopic suture is one of the most frequently performed task in minimally invasive surgery. It is used to close the incisions made during the surgical procedure. This task need an high level of surgeon experience in order to be carried out correctly reducing unwanted side effects. It needs much training.

A new trend in the development of virtual surgical simulators is represented by "serious games". A serious game is a computer game whose primary purpose is not entertainment, but teaching and learning. Although virtual simulators and serious games are conceptually similar and the same technology (hardware and software) can be used, the serious game approach introduce an entertainment factor and include some of the highlights typical of a videogame: challenge, risk, reward and defeat.

Serious gaming in healthcare and surgery has the goal to educate and train people about treatments, medical and surgical procedures, involving them with an entertainment factor typical of a videogame.

In this paper we present a serious game for training surgeons on suturing in laparoscopic surgery. In particular, our system is focused on an accurate physical modeling of the virtual environment and on the definition of a set of parameters used to assess the level of skills developed by the trainees. A pair of haptic devices has been utilized in order to simulate the manipulation of the surgical instruments. NVIDIA PhysX physics engine is used to simulate the physics of the simulated environment and Ogre3D is used for graphical rendering.

## 2 Surgical Training

Medical professionals for centuries have used a training model based on apprenticeship. With this training approach the trainee observes a procedure made by an expert physician and then practices it under the teacher or an expert supervision.

With this traditional approach, many different tools and techniques have been deployed to provide added value to the training process, such as using animals or cadavers or by practicing on mannequins. However, the interactions that occur in an animal’s or cadaver’s tissues differ from those of living humans due to varying anatomy or absence of physiological behaviour. This type of training can also raise some ethical issues. Mannequins that simulate part or all of a patient anatomy provide a limited range of anatomical variability and also a different response from the living human tissue.

An alternative approach that is becoming more and more accepted by the medical community consists in the use of a virtual reality simulators that can train practitioners on a virtual patient and permit to have a live feedback on the performed procedure. This feedback can then be used to refine the required skills until the operator reaches a target level of proficiency before doing the required procedure on the real patient. In addition, virtual simulations can provide the user the possibility to practice the surgical procedure on rare or difficult medical cases or on virtual models of patients with unconventional anatomy.

3D virtual models offer also the opportunity to be customized. In fact they can be derived from patient medical data in order to replicate the patient's real anatomy and produce a realistic simulation environment.

Laparoscopy is a minimally invasive surgical procedure performed on the patient body through small incisions on the patient skin using long thin tools. The surgeon’s view is provided by means of a camera inserted into the patient body. With this kind of "indirect" view and with the manipulation of long surgical instruments, the distance between surgical tool and the organ is difficult to be estimated. For this reason in this surgery field training with virtual simulator is very important [2]. Practitioner needs a long training period using commercial simulators before performing the operation on the real patient.

## 3 Virtual Surgical Simulators

In the field of surgical simulation, Wang et al. [5] present a physics-based thread simulator that enables realistic knot tying at haptic rendering rate. The virtual thread follows Newton's law and considers main mechanical properties of the real thread such as stretching, compressing, bending and twisting, as well as contact forces due to self-collision and interaction with the environment, and the effect of gravity.

Webster et al. [6] describe a new haptic simulation designed to teach basic suturing for simple wound closure. Needle holders are attached to the haptic device and the simulator incorporates several interesting components such as real-time modeling of deformable skin, tissue and suture material and real-time recording of state of activity during the task.

Le Duc et al. [7] present a suturing simulation using the mass-spring models. Various models for simulating a suture were studied, and a simple linear mass-spring model was determined to give good performance.

Choi et al. [8] explore the feasibility of using commodity physics engine to develop a suturing simulator prototype for manual skills training in the fields of nursing and medicine. Spring-connected boxes of finite dimension are used to simulate soft tissues, whereas needle and thread are modeled with chained segments. The needle insertion and thread advancement through the tissue is simulated and two haptic devices are used in order to provide a force feedback to the user.

Lenoir et al. [9] propose a surgical thread model for surgeons to practice a suturing task. They first model the thread as a spline animated by continuous mechanics. Moreover, to enhance realism, an adapted model of friction is proposed, which allows the thread to remain fixed at the piercing point or slides through it.

Shi et al. [10] present a physics-based haptic simulation designed to teach basic suturing techniques for simple skin or soft tissue wound closure. The objects are modeled using a modified mass-spring method.

LapSim [24] is a commercial surgical simulator that offers a complete portfolio of laparoscopic procedure exercises. It has a modular structure and comprises also a module for laparoscopic suture training.

## 4 Serious Games

Serious games usually refer to games developed for user training and education. In 2005 Stokes [3] defined serious games as: "games that are designed to entertain players as they educate, train, or change behaviour". They are designed to run on personal computers or videogame consoles. Today they can be played also on smartphones.

Serious games provide an high fidelity simulation of particular environments and situations that focus on high level skills that are required in the real world. They present situations in a complex interactive context coupled with interactive elements that are designed to engage the trainees.

Strengths and weaknesses of videogames are also transferred to serious games. Further benefits of serious games include improved self-monitoring, problem recognition and solving, improved short-and long-term memory, increased social skills and increased self-efficacy [4].

In contrast to traditional teaching environments whereby the teacher controls the learning (teacher centered), the serious games present a learner centered approach to education in which the trainee controls the learning through interactivity.

Serious game engagement may allow the trainee-player to learn via an active, critical learning approach. Game-based learning provides a methodology to integrate game design concepts with instructional design techniques with the aim to enhance the educational experience.

Virtual environments and videogames offer students the opportunity to practice their skills and abilities within a safe learning environment, leading to a higher level of self-efficacy when faced with real life situations where such skills and knowledge are required.

Serious games should provide a balanced combination between challenge and learning. Playing the game must excite the user, while ensuring that the primary goal (acquiring knowledge or skills) is reached seemingly effortlessly, thus creating a 'stealth mode' of learning. Players are challenged to keep on playing to reach the game's objective.

Although game-based learning is becoming a new form of healthcare education, scientific research in this field is limited.

Dental Implant Training Simulation [11], developed for the Medical College of Georgia and funded through a grant by Nobel Biocare, is a groundbreaking project created to better teach and train dental school students and dental professionals on patient assessment and diagnosis protocol and to practice dental implant procedures in a realistic, 3D virtual environment. The game-based simulation has the aim to improve dental student learning outcomes in the area of diagnostics, decision-making and treatment protocols for enhanced patient therapy outcomes and risk management.

Total knee arthroplasty [12] is a commonly performed surgical procedure whereby knee joint surfaces are replaced with metal and polyethylene components that serve to function in the way that bone and cartilage previously had. The serious game has been designed to train orthopedic surgical residents on surgical procedures, and to gauge whether learning in an online serious gaming environment will enhance complex surgical skill acquisition.

Qin et al. [13] realized a serious game to train blood management in orthopaedic surgery context to orthopaedic surgeons. The serious game uses two haptic interface for the user interaction and comprises two practice games where the player develop the required hand-eye coordination using the haptic interface. In the third game the user play as a surgeon and three modality were provided: training mode, time-attack mode and collaborative mode. The game uses a Mass-Spring model for tissue deformation modeling and a blood flow distribution model based on human physiology.

Cowan et al. developed a serious game for off-pump coronary artery bypass grafting cardiac surgical procedure (OPCAB) training [14]. In the game the player is placed in the operating room with the role of cardiac surgeon and must execute surgical procedure.

Qin et al. presented another serious game [15] to train radiologist in the ultrasound-guided needle placement procedure. They used a block based construction scheme in order to generate game scenarios and a novel texture-based image synthesis technique in order to simulate corresponding ultrasound images. The game was evaluated over a group of 21 participants and this study shows that the serious game approach is useful for surgical skills teaching to surgical novices.

Serious gaming can be used to enhance surgical skills. Ideally, these training instruments are used to measure certain parameters and to assess the trainees' performance. In these games, strict requirements should be met and the interpretation of the game metrics must be reliable and valid. Games used to train medical professionals need to be validated before they are integrated into teaching methods and applied to surgical training curricula [17].

## 5 Technological Platform

The serious game for laparoscopic suturing training was developed using OGRE 3D graphics engine [16], NVIDIA PhysX for physical modeling of the objects and HAPI library for haptic interactions and force feedback rendering.

PhysX [17] is a real-time physics simulation framework developed from NVIDIA. A major advantage of this physics engine is the support of hardware acceleration when a compatible Graphics Processing Unit is installed. Developers can instruct the engine to utilize the processing power of the GPU in order to perform physics computation and to relieve the CPU for other tasks.

PhysX uses a position-based approach for the body dynamics management in order to reduce the instability problems that could make unnatural the results of simulation and so the resulting environment [18].

The PhysX engine supports the simulation of both rigid bodies and soft objects, including cloth and fluids. It employs a scene graph to manage the objects in a virtual environment.

In order to provide a force feedback to the user, an haptic interface is used in our simulation. In our developed solution it is possible to use two SensAble Phantom Omni or two Novint Falcon haptic devices.

The choice of the preferred haptic devices is possible through the use of the multi-device HAPI library. This library has the advantage to be open-source and cross-platform. It supports many commercial haptic interface and the user can extend this compatibility writing its own library extension. In order to improve simulation results it is better to use two Phantom Omni devices that have a larger workspace and are provided of 6 DOFs [19].

## 6 Simulation Models

One of the most important thing in surgical simulation is the real-world reproduction fidelity. The reproduction fidelity is measured not only in terms of graphical rendering fidelity but also in terms of physical behaviours simulation. Objects and materials should react to forces and solicitation like in the real world.

To achieve this goal it is necessary to use a physically-based simulation. This approach considers the physical properties of the object materials as well as its geometrical shape in a mathematical model that tries to reproduce the real world. Generally more are real world reproduction fidelity constraints more computational resources are needed in order to obtain an accurate simulation. These constraints are generally in contrast with the requirement to have a "real-time" interactive simulation which can responds to the user interaction.

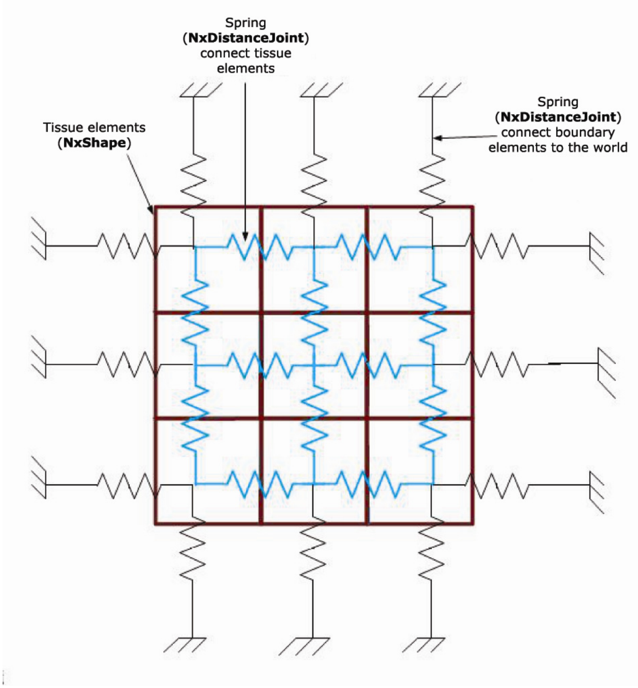

**Fig. 1.** Tissue modeling using the mass-spring method

### *Tissue Modelling*

In the simulation, virtual tissues has been modeled using the mass-spring method [20]. Other models were also developed for this purpose but this one was chosen for its computational complexity. The tissue is represented as a three-dimensional net of point masses connected each other with springs.

Tissue deformation is based on the dynamics of the masses, and on the elasticity and damping factor of the springs that connect these masses. The law that describes the dynamic of each single point of mass (node) is the Newton law:

$$m_i \frac{d^2 \boldsymbol{x}_i}{dt^2} + c_i \frac{d\boldsymbol{x}_i}{dt} + \boldsymbol{F}_i^{int} = \boldsymbol{F}_i^{ext} \qquad i = 1, \dots, m$$

with

$$\boldsymbol{F}_i^{int} = \sum_{j \in N_s} \frac{k_{ij}\left(\left|\boldsymbol{d}_{ij}\right| - l_{ij}\right)}{\left|\boldsymbol{d}_{ij}\right|} \boldsymbol{d}_{ij}$$

In these equations $\boldsymbol{x}_i$ represents the displacement of i-th node with respect its position in quiet state, $m_i$ is the mass of the point, $c_i$ is the damping factor of the i-th node, $\boldsymbol{d}_{ij}$ is the distance vector between i-th and j-th points, $k_{ij}$ and $l_{ij}$ are respectively the stiffness and length of the spring in the quiet state between i-th and j-th nodes and $\boldsymbol{F}_i^{ext}$is the sum of the external forces that acts on the i-th node. $N_s$ is the set of the nodes directly connected to i-th node with a spring. These equations are discretized and solved iteratively on the computer with a 4th order Range-Kutta method.

Additional springs have been used in order to fix the grid of springs in the virtual space. These springs allow the tissue to resume its original shape when the effect of deformation is removed. Fig. 1 shows the model of the tissue with the mass-spring method. In the intersection point of the springs there are the ideal point masses. Usually, in this kind of modeling masses have infinitesimal size, but PhysX engine does not allow the definition of dimensionless objects. For this reason a box of finite size has been used for the creation of a single tissue element.

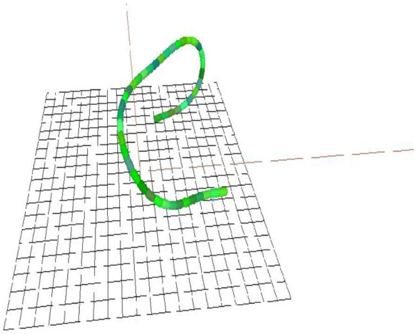

**Fig. 2.** Thread model

Another advantage that comes with the use of a mass-spring model is that a topological modification of the net produce a simple modification of the model equations. For example, the cut of the tissue surface produces a modification of the equations of the only nodes directly connected to those involved in the cut. Anyway this produces also a disadvantage because global modifications are hard to propagate because they require many simulation iterations.

Tissue rendering is obtained using Ogre3D [21]. Ogre3D is a scene oriented, open source 3d graphics engine. It supports only graphical rendering process and is compatible with many library for haptic, sound, etc. rendering and also physics computation. Ogre3D is a cross-platform library and can be used with Windows, Mac OS X and Linux platforms.

In Fig. 2 is shown the model of the thread.

### *Thread Modelling*

The main technique used to model the dynamics of the surgical thread in virtual simulations is known in literature as “follow-the-leader” [22]. With this technique the thread is modeled by means of a chain of cylinders connected by joints that allow to simulate the bending of the thread.

At each step of simulation, when an external force is applied to a cylinder, the new position of this cylinder is calculated, and, using the follow-the-leader approach, the new positions of all cylinders are computed. In addition also the collisions between elements of the thread are detected and the new configuration of the entire thread is displayed.

As for the tissue, also for the thread the PhysX features are exploited in order to manage the dynamics of the thread (calculation of position and collision detection).

To simulate the flexibility of the thread, two adjacent cylinders are connected through a spherical joint, which allows the rotation of the elements relative to each other. A spherical joint, as shown in Fig. 3, is a constrains where two points located on two different rigid bodies must coincide in one point in space; a spherical joint has 3 free DOFs and 3 blocked DOFs. The visual model of the suturing thread is achieved through the rendering of all elements of the chain.

The use of spherical joints could led to strong oscillations when the thread is subjected to strong stretching forces. This is because spherical joints are temporarily disconnected when subjected to strong forces. To reduce this problem we modified the inertial tensor of thread elements to increment the inertia of each element.

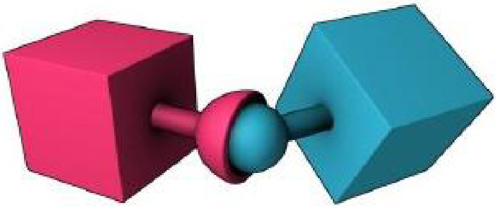

**Fig. 3.** The spherical joint used in order to simulate the flexibility of the thread

## 7 Serious Game for Laparoscopic Suturing Training

The aim of the developed serious game is to teach to surgeons the laparoscopic suture technique in minimally invasive surgery. An assessment module in the game were also provided to evaluate surgeon performance during the training phase.

To execute the surgical procedure two clamps are provided in the virtual environment. They are controlled by two haptic interfaces and should be used in order to pick the needle and execute the suture like in the real world.

After playing the serious game simulation the user should:

- acquire a good eye-hand coordination, that is very important in laparoscopic surgery;
- improve the ability to manipulate the surgical instruments;
- learn the techniques for performing the suture node.

**Table 1.** Parameters used to assess the player's performance

| **Parameter** | **Description** |
|---|---|
| Duration time | It is the time elapsed between the first contact of the needle with the tissue and the completion of the node. Less time the surgeon spends to complete the procedure and greater is the evaluated skill. |
| Accuracy error | This parameter describes the maximum distance between the ideal point (indicated by a marker) and the real point of entry of the needle into the tissue. Smaller is the error and higher is the quality of the node. |
| Force peak | This number is the value of the maximum force used during the simulation in order to pierce the tissue by means of the needle. |
| Tissue damage | This value represents the sum of the forces applied to the tissue over the threshold of breakage of the tissue. |
| Angle of entry | This parameter is the difference between the normal to the surface and the tangent at the point of the needle entry. |
| Overall score | This parameter is determined by the average of all previous specified parameters. |
| Needle total distance | This value represents the total distance traveled from the needle in order to complete the task. Shorter is this distance and greater is evaluated the skill of the surgeon. Anyway this parameter is not included in the calculation of the quality assessment of the suture task. |

Before developing the serious game some requirements were defined. These guided the entire development process and are:

- Simulation: the system should simulate as much as possible the real appearance and behavior of a real human tissue and suture thread;

- Configuration: the size of the tissue, the number of elements of the thread, the number and position of the fiducial points on the tissue and the time duration of the simulation must be specified before starting the simulation. These parameters are all stored in an XML configuration file;
- Haptic device - surgical forceps interaction: the user must to be able to move the virtual surgical forceps by means of the haptic device;
- Skill evaluation: the game must implement algorithms for measuring the skill of the user during the execution of the surgical procedure.

In the assessment of a suturing procedure it is necessary to consider some parameters that should be evaluated. These parameters are not extracted from the medical literature, which does not specify any quantitative metrics for evaluating the performance of this task, but were expressly defined for this serious game.

Some numerical indicators can be achieved by the physically-based virtual simulation. The Table 1 summarize the parameters used to assess the player's performance.

The software architecture of the serious game has been developed using the architectural pattern Model-View-Controller (MVC), whose use is not limited to the development of web applications, but also to virtual simulators [23].

The model manages the behavior and objects of the virtual environment, responds to requests for information about its state and responds to instructions to change state (Fig.4).

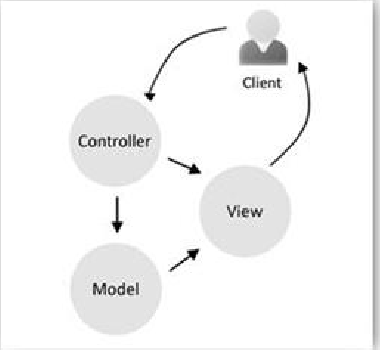

**Fig. 4.** Model-View-Controller pattern representation

The view renders the model into a form suitable for interaction and is managed by OGRE 3D graphical engine.

The controller accepts input from the user and instructs the model to perform actions based on that input. There are two subcontrollers:

- The controller of the physical simulation that applies the laws of the physics to the elements of the model (by changing the position, velocity and acceleration of the objects) and handles the collision detection between objects in the scene. This controller is implemented by the PhysX library.

- The controller of the haptic simulation that allows the communication between the model and the haptic device. This controller returns the forces, but is not responsible for the calculation of these that are computed by the controller of the physical simulation.

In Fig. 5 is shown the monitor of a pc with the serious game interface loaded and the two Novint Falcon haptic devices.

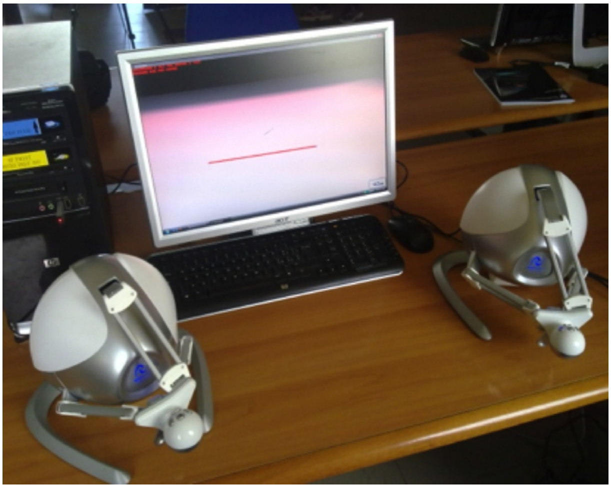

**Fig. 5.** The serious game using two Novint Falcon haptic devices

## 8 Conclusions and Future Work

This work describes the design and development of a first prototype of serious game for training surgeons on suturing in laparoscopic surgery.

We focused our attention on as more as possible accurate physical modeling of the objects involved in the serious game (the virtual tissue, the suture thread and needle). Then we defined a methodology to evaluate and measure the skills of the trainee. The surgical instruments manipulated by the surgeon are replaced in the serious game by two haptic interfaces. These interfaces control the movements of the virtual tweezer that are used in order to manipulate suture thread and needle.

We cannot compare our surgical simulator with complete and complex commercial products like the LapSim. The first reason is that we focused our attention on a particular step of the laparoscopic procedure (suturing) and ignored all the other steps of laparoscopic surgery that require however an accurate training. This choice and the use of commercial haptic interfaces permitted to mantain very low the cost of the simulator. The second reason is that we've structured our simulator as a serious game to engage and motivate the players to improve their performance. We made this choice because we want to evaluate in a successive study the usefulness of a serious game training approach in laparoscopic suture training.

In the future the system can be improved with a more accurate modeling of the interaction between the tissue and suture thread. Algorithms for skills evaluation can also be improved with a software module that stores the results of users training sessions in order to evaluate the progress of performance in the execution of suturing task. We also plan to substitute the current haptic interfaces with more expensive ones to ensure a bigger dimension of the player's workspace. These interfaces can be then modified to include real surgical instruments in the handle in order to obtain a more realistic simulation. Last we want try to evaluate the game training usefulness with medical students and expert surgeons to understand if this can represent a valid training approach.

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