# Towards a Virtual Basic Laparoscopic Skill Trainer (VBLaST)

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**Abstract.** Surgical skill training is a long and tedious process of acquiring fine motor skills. To overcome the drawbacks of the existing toolbox trainer systems, we develop, for the first time, a virtual basic laparoscopic skill trainer (VBLaST) whereby tasks, such as the ones available in the FLS toolbox system, may be performed on the computer.

**Keywords.** Computer Graphics, Interaction techniques, Simulation and Modeling, Haptic I/O

## Introduction

With its many advantages of minimal postoperative pain, few postoperative adhesions, minimized blood loss, low risk of surgical complications, short hospital stay, and early return to normal activities, minimally invasive surgery (MIS) has revolutionized general surgery in the past decade in treating both malignant and benign diseases. Surgical skill training is a long and tedious process of acquiring fine motor skills. The Society of American Gastrointestinal Endoscopic Surgeons (SAGES) has recently introduced the Fundamentals of Laparoscopic Surgery (FLS) training tool box [1], consisting of a box covered by an opaque membrane through which two 12 $mm$ trocars are placed on either side of a 10 $mm$ zero-degree laparoscope connected to a video monitor. Inside the box five premanufactured tasks including peg transfer, pattern cutting, ligating a loop and suturing can be performed. The mechanical tool box shown in Figure 1 is similar to the FLS system and is used in training the same set of tasks.

Potential drawbacks of such mechanical toolbox systems are: the training material has to be constantly replaced after it is cut or sutured, objective quantification of skill is difficult and unless specialized and expensive stereo cameras are used, the images obtained are in 2D and therefore these systems are not suitable to train for robotic surgical systems such as the Da Vinci$^{TM}$. To overcome these problems, we develop, for the first time, a virtual basic laparoscopic skill trainer (VBLaST) whereby tasks, such as the ones available in the FLS system, may be performed on the computer.

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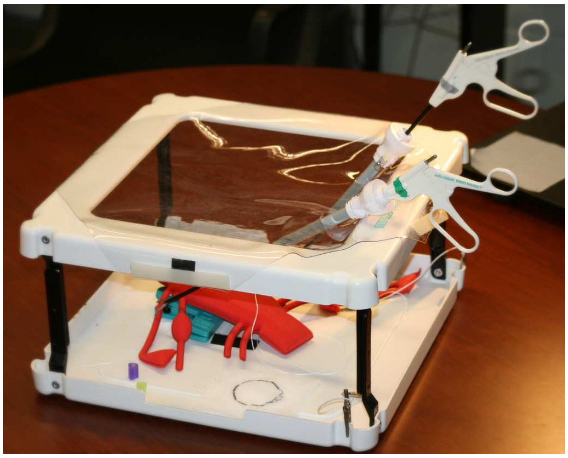


**Figure 1.** Mechanical training toolbox.

## 1. Related work

Most existing work on laparoscopic skill trainers focus on the metrics for the student performance measurement [2]. They often present a set up of the real toolbox for the participants to perform a number of tasks. Several surgical simulators have already been validated for resident and surgeon training. Some are limited to 2D video-based training [3]. The most notable of these is the McGill Inanimate System for Training and Evaluation of Laparoscopic Skills (MISTELS). This system involves performing laparoscopic simulated tasks on inanimate objects within a box trainer. Such tasks have been extensive tested and validated as an effective training tool. A reduced set of the MISTELS tasks has been adapted to the FLS training box. Figure 2 illustrates the four tasks that can be performed in the box.

The use of stereo vision has been shown to benefit performance of surgical tasks, while virtual environments have significant advantage over the mechanical toolbox systems [4], [5]. The Minimally Invasive Surgery Trainer - Virtual Reality (MIST-VR) program is an example of these kinds of trainers. Potential drawbacks of these trainers include their high cost, lack of tactile feedback, and lack of stereoscopic visualization.

## 2. Methods

Consistent with the FLS system we have developed the following tasks within VBLaST (see Figure 3):

**Peg transfer (Figure 3a):** Each of 6 virtual rings may be lifted from a virtual pegboard with the left hand, transferred to the right hand and placed on another pegboard.

**Pattern cutting (Figure 3b):** A 4 $cm$ diameter premarked circular pattern may be cut out of a 10 $cm$ Œ 10 $cm$ piece of virtual gauze suspended between alligator clips.

**Ligating loop (Figure 3c):** A 3-dimensional tubular structure is presented in space. Using bimanual manipulation a virtual loop is securely fashioned about a pre-drawn line on the tubular structure.

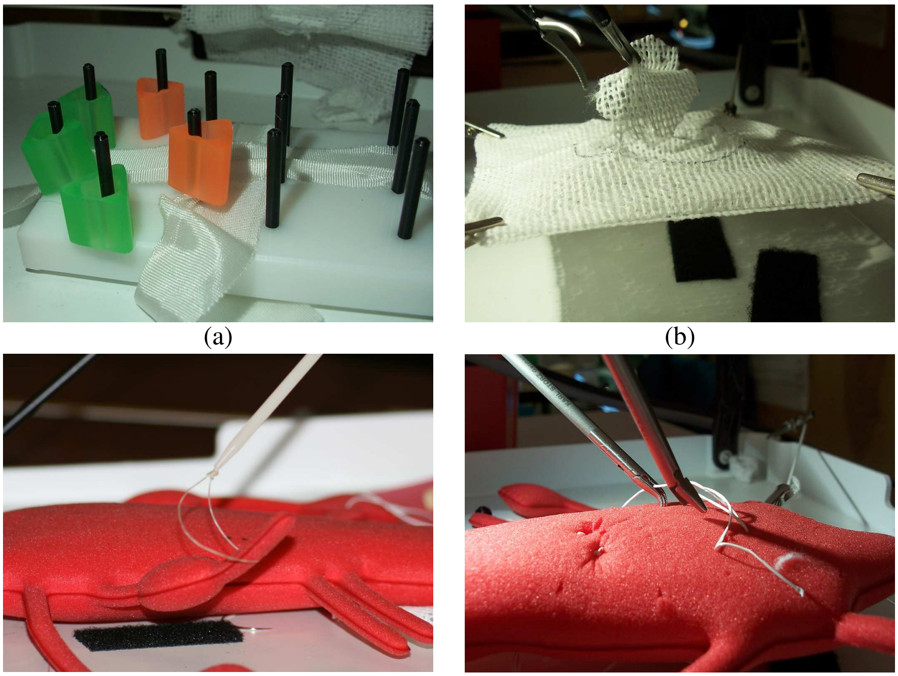

(a) (b) (c) (d)

**Figure 2.** The 4 MISTELS tasks used in the FLS toolbox: (a) peg transfer; (b) circular pattern cutting; (c) ligating loop; (d) suturing.

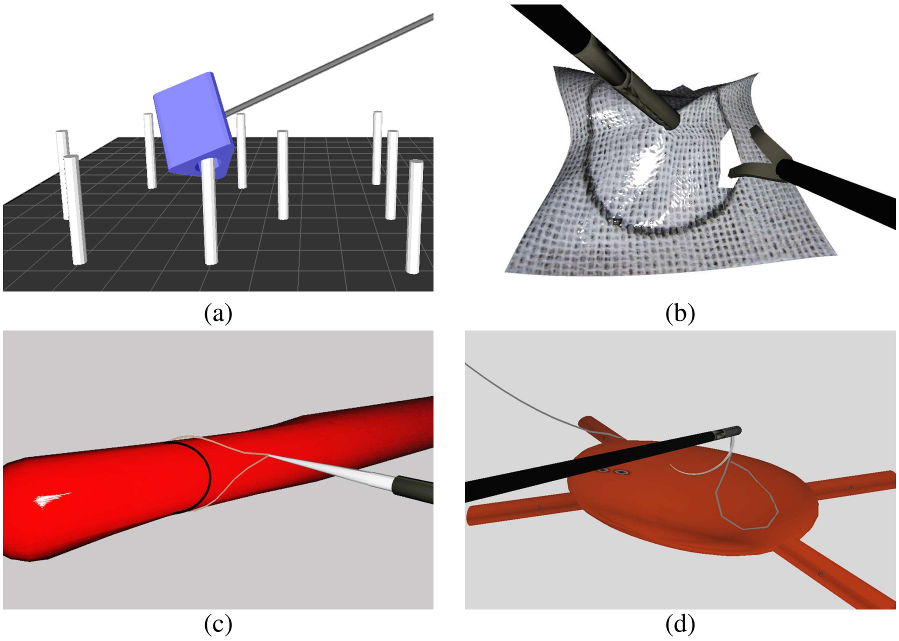
**Suturing (Figure 3d):** A virtual suture is tied using either an intracorporeal or extracorporeal knot, using 3-dimensional bimanual manipulation with a curved needle.

### 2.1. *Interface*

A stereoscopic visio-haptic workstation has been developed including two Phantom$^R$ Omni$^{TM}$ force feedback devices and a 3D display interface from Planar Systems, Inc. There is provision to turn the stereoscopic display on (VBLaST2D) and off (VBLaST3D) at will for the same task. Figure 4 shows the whole system. During the simulation, the participants use the Phantoms to control the virtual surgical instruments to interact with the virtual training materials. On the virtual side, the instruments represented in the system are tissue graspers, suture graspers, scissors and the ligating loop. On the hardware side, we have developed a plug-and-play interface that allows us to instrument real surgical hand tools and attach them to the Phantom stylus gimbal using 6.3 $mm$ headphone jacks.

### 2.2. *Collision detection*

Collision detection and dynamic response computation in a virtual environment are necessary so that one can pick, move or even cut objects at the same time that effort responses are generated. Collision handling is the key to the whole interactive simulation system, and due to the high update rate required for the haptics device (around 1000 $Hz$),


(a) (b)

(c) (d)

**Figure 3.** The 4 VBLaST tasks: (a) peg transfer; (b) circular pattern cutting; (c) ligating loop; (d) suturing.

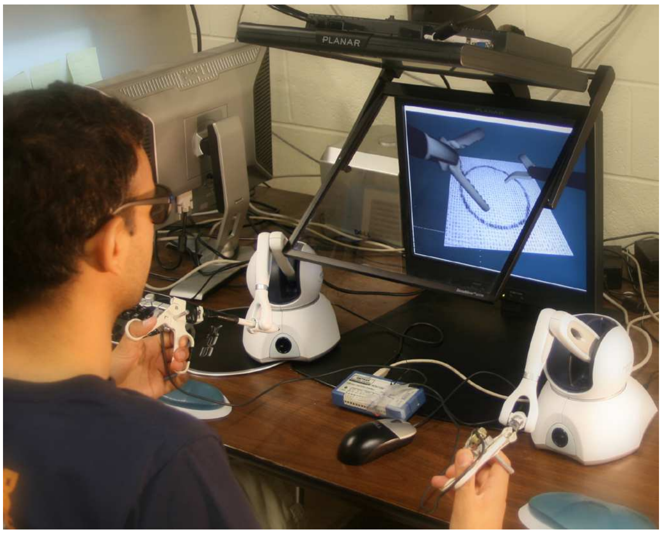


**Figure 4.** The VBLaST workstation.

the algorithm must be very efficient. An efficient dynamic point algorithm is used for line-based collision detection and response, readers can refer to [6] for more details. The basic idea of the algorithm is that only one point is used for collision detection and response, but this point is constrained to lie on a line at a location which is instantaneously closest to the mesh. The line is represented by its end points and a dynamic point, which is chosen to be the closest point on the line to any potentially colliding triangle. The dynamic point position on the line is updated at haptic frequencies and hence to the user, due to inherent latencies of the order of 1 $ms$ in the human haptic system, it is virtually indistinguishable from a line.

### *2.3. Physics-based modeling of VBLaST tasks*

Various physics-based algorithms are used for interaction with the various virtual objects. The peg-transfer task relies on implementing correct rigid body dynamics (Figure 3a). Momentum and torques are computed depending on interaction with the tools and pegs. Collisions produce impulses, which changes the trajectory and spinning when the rings are released and provide force-feedback when they are held by a tool. For the other three tasks, however, deformations are present. We use mass-spring-damper models to simulate deformations and penalty forces to handle contact with deformable objects.

The gauze model for the pattern cutting task (Figure 3b) is a textured mass-spring square membrane attached at the corners. It undergoes deformation as it collides with the scissor shaft and blades. Whenever the same triangle is in contact with the two blades and the blades are closing, the springs around the triangle are removed, causing the gauze to open up at that spot.

In the suturing task (Figure 3d), collision detection for the needle-tissue interaction is performed using a needle discretized into line segments as described in section 2.2. When the tip of the needle is in contact with the tissue, the contact force is computed. If this force exceeds a threshold value, the tissue is penetrated. After the first penetration, and while a portion of the needle is inside the tissue, physics-based constraints are applied, and any displacement out of the needle axis is penalized. The penalty force is implemented as a spring attracting the node to its projection on the needle-axis. The suture-thread, in turn, is modeled as a 1D mass-spring structure. To allow the thread to withstand axial tension and smooth bending with a finite curvature much like the real suture, each mass point is connected with three front and three rear mass points by springs.

Interestingly, the above strategy does not work for the ligating loop problem (Figure 3c) since we would have to deal with an elastic loop whose shape is hard to maintain without using stiff springs which are instable. We have developed a new strategy combining a rigid loop structure with a simple mass spring, anchoring the mass points to positions on the rigid loop with springs. This model provides natural looking behavior with very high efficiency.

## 3. Results

We have implemented an interactive PC-based surgical simulation framework and tested it on an Intel(R) Core2 Quad 2.66GHz machine with a GeForce 8800 GTX graphics card. Customized vertex and pixel programs are used for textured shading, which provides state of the art interactive graphics realism. This simulator utilizes two force feedback devices to provide bimanual surgical tasks, and a dual polarized monitor based stereo vision system.

The system runs at haptic frequencies and displays graphics at 30 $Hz$ for each monitor/eye. Such frequencies provide smooth graphical displays with no flickering and vibration-free haptics rendering. The haptic frequencies are essentially dependent on the performance of the collision detection. The algorithm we use is based on line collision and depends only on the number of lines we are checking for collision. For the cutting task, e.g., three lines are used (the long shaft of the instrument, the upper and lower blades). As the task is bimanual, we eventually have six lines to check. The physics-based simulation frequencies depend on the model complexity and integration methods and vary considerably, but the material parameters are tuned so that it is high enough to deliver very dynamic and responsive deformations and contacts.

## 4. Conclusions/Discussion and Novelty

We have developed, for the first time, a virtual basic laparoscopic skill training (VBLaST) simulator which allows training for both traditional minimally invasive surgical procedures as well as procedures on the Da Vinci$^{TM}$ robotic surgery system. The system provides realistic stereo graphics interface and bimanual haptics interface to provide an immersive training environment.

The VBLaST has significant advantages over the FLS trainer boxes, which are used for laparoscopic surgical training. The next step in this research is to actually use the VBLaST training system to train novice surgeons and compare their progress with experienced ones for both 2D and 3D visualization. We are also developing a glove-based tracking system that would allow us to capture the hand and finger motions of the trainees for the purpose of objective quantification of skill training.

## Acknowledgements

Support of this research by grant R01 EB005807-01 from NIH/NIBIB is gratefully acknowledged.

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