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A Virtual Reality Surgical Trainer for Navigation in Laparoscopic Surgery

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Abstract. A virtual reality trainer was designed to familiarize students and surgeons with surgical navigation using an angled laparoscopic lens and camera system. Previous laparoscopic trainers have been devoted to task or procedure training. Our system is exclusively devoted to laparoscope manipulation and navigation. Laparoscopic experts scored better than novices in this system suggesting construct validity. The trainer received favorable subjective ratings. This simulator may provide for improved navigation in the operating room and become a useful tool for residents and practicing surgeons.

1. Background/Problem.

All surgical procedures require some degree of visual navigation within an operative field. Different visuospatial skills however, are required for navigation with a laparoscopic lens within the complex three-dimensional environment of a body cavity [1]. In traditional open surgery, unaided eyes track and focus without higher cognitive input. In video-endoscopic or laparoscopic surgery, the "vision" of the operation must be directed manually, requiring a different set of skills and possibly higher cognitive function.

Most commercially available angled laparoscopic lens systems consist of a long slender lens that allows change in direction of view through rotation of the lens itself. The angled view allows for another degree of freedom for inspection, i.e. the ability to look around corners. This is coupled to an independently rotating video camera. The camera and lens system must be rotated independently in order to achieve the desired angle of view while maintaining correct right-side-up orientation. The function, orientation, and manipulation of an angled laparoscopic lens in combination with an independently rotating camera system may not be intuitive.

Several simulators have been developed for training laparoendoscopic surgery, but most focus on task or part-task trainers, designed to provide instruction in the motor component required for laparoscopic surgery [2-7]. One such computer-based trainer is the MIST VR, which was designed to train in the special "hand-eye" coordinated movements that are basic to laparoscopic surgery [8]. Aside from motor skill learning, the acquisition of visuospatial skills may be important to operating surgeons [9-13]. Our simulator is concerned with the visuospatial issues of manipulating an angled laparoscope. To date, no simulator has been developed for instruction in laparoscopic navigation.

Often, the duty of “driving the camera” is delegated to an assistant or a junior member of the team while the operating surgeon performs the procedure. In this arrangement, the camera / lens operator must serve as the eyes for the entire surgical team. A facile understanding of the function, operation, and manipulation of the laparoscope is essential. While stationary and robotic camera-positioning devices are available, the surgeon must still have a fluid understanding of the manipulation of the laparoscope. A computer-based simulator designed to replicate the maneuvers necessary and provide instruction in angled laparoscopic lens “driving” in a controlled setting would theoretically provide for a better understanding of the camera lens system and more efficient navigation in the operating room.

The purpose of this project was to develop a computer-based training system that would provide instruction to relative novices at laparoscopic navigation using an angled lens. The software was designed to challenge the participants so that a wide variety of angular and rotational maneuvers would be required to identify visual targets while maintaining right-side-up orientation. Additionally, a timer and error scoring system was developed and included.

2. Methods and Tools.

2a. Hardware Platform.

The Virtual Laparoscopic Interface (VLI) (Immersion Corporation, San Jose, CA), was utilized as the input device as it provides a fast, effective means of tracking simulated laparoscopic motion. The VLI is a human-computer interface tool designed for virtual reality (VR) simulations of laparoscopic and endoscopic surgical procedures. The frame unit acts as a sensored trocar that is connected via a serial port on a Windows™ NT workstation with dual pentium processors and Wildcat OpenGL™ graphics. Different surgical tool handles can be attached to the sensory unit. The VLI tracks the motion of a pair of laparoscopic surgical instruments, each moving in 5 degrees of freedom. The trocar sensors provide an angular resolution of 0.088 degrees, a linear position resolution of 0.0005 inches, and can move up to 8 inches along the insertion axis. The latency is less than 1 ms. The VLI system provides a fast, effective means of tracking laparoscopic and endoscopic surgical procedures.

2b. Modeling and Software.

The task for the laparoscopic surgical training session entails identifying randomly placed arrows in an "endotower". The endotower is a three dimensional (3D) block tower with holes drilled out within its various arms (Figure 1). The endotower provides a relatively complex three-dimensional structure for exploration with the angled lens. In the simulator, 3D arrows of varying colors and directional orientation are randomly placed inside the cylindrical cut-outs. Arrows were chosen as the targets so that participants would be required to maintain right-side-up orientation in order to be able to properly identify them. Arrows could have one of four colors and six directional orientations giving 24 possible combinations. Six arrows were randomly placed on and within the virtual endotower (Figure 2).

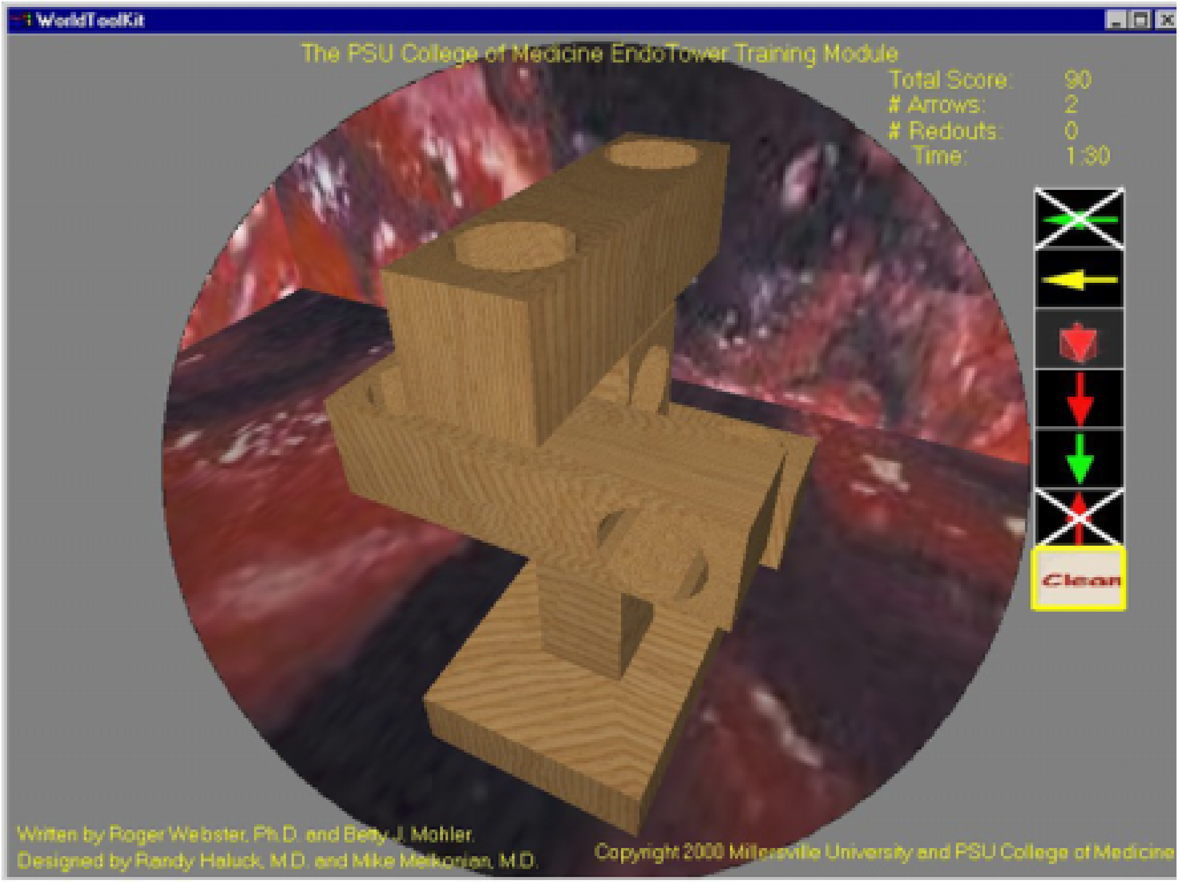

Figure 1: The three dimensional endotower

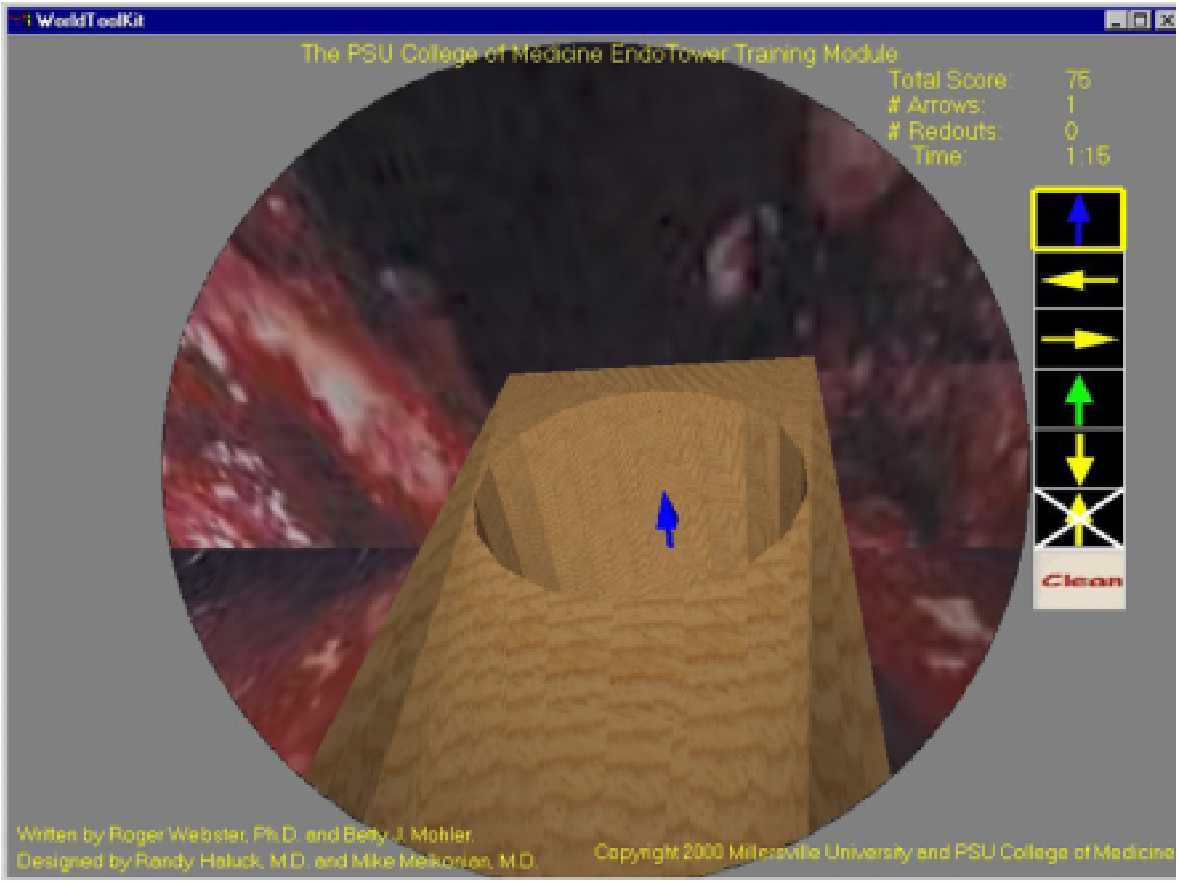

Figure 2: A randomly paced arrow within the virtual endotower

To operate the simulator, the practicing surgeon holds one of the VLI laparoscopic tools, which simulates the angled lens laparoscope. Rotation of this tool rotates the angle of view from the longitudinal axis of the virtual laparoscope. The other laparoscopic tool is used to simulate the laparoscopic camera and rotations of this instrument change the up and down orientation of the surgeons’ view. These separations of functions, in contrast to the coaxial controls of a standard laparoscopic camera, are due to the limitations of the present VLI hardware. In the virtual world, the user's viewpoint is placed at the tip of the laparoscopic tool. Due to the 3D nature of the endotower and the cylindrical cutouts, identifying all the arrows entails manipulating the laparoscope to many different and challenging orientations and positions.

Once a target arrow is identified, the student selects the matching arrow from a list. The user's score goes up for each arrow correctly identified. Any collision with the endotower causes the view to become fuzzy and blurry with 'red out', simulating touching the laparoscope to an organ and smudging the lens with blood (Figure 3). The learner must withdraw the virtual laparoscope and await a cleaning mode, thus penalizing the user’s score in terms of time efficiency and errors. The scoring mechanism keeps track of the amount of time to correctly identify the color and orientation of each arrow, the number of times the users dirties the camera lens (collides with the endotower), and the rotational efficiency. It also records the amount of time to complete the entire training procedure.

The three dimensional models of the virtual laparoscopic tool and endotower model were built in 3D Studio Max and are stored as 3ds files. These models are loaded into the graphics simulation. The graphics software modules make calls to EAI/Sense8's WorldToolkit API of OpenGL calls.

Another software module records the motions of the user by continuously recording the positions and orientation of the endoscope and the lens rotations. Thus, 3D graphics can be used to replay the movements, showing the user what they did during the training session. The replay can be done either from the laparoscopic viewpoint or from a bystander viewpoint.

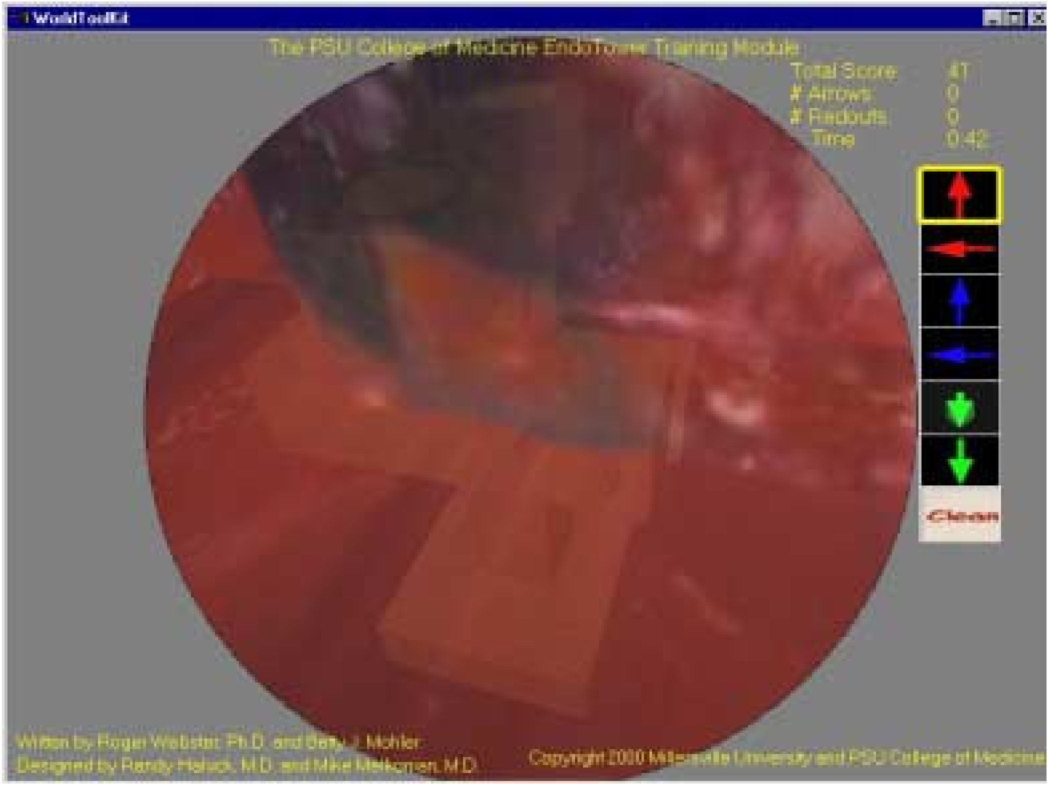

Figure 3: Simulating ‘red-out’ when the user collides with the endotower

3. Results.

Two small groups of surgeons, novices and experts, were enlisted to test the fidelity of the simulator and test the validity of the scoring mechanism. Novices included medical students who had never performed a laparoscopic procedure. Experts included the surgical chief residents and minimally invasive surgical staff. All of the users found that the graphics of the simulator were adequate, however, 86% of the users found the hardware tools/handles interface to be inadequate for this type of simulation. Seventy-one percent of the users believed that the laparoscopic surgical endotower training simulator would be useful as a training tool for laparoscopic surgery and that it has the capability of teaching a novice the 30 degree angle scope.

All of the users went through a training program with an expert instructor, which included practice sessions. The two groups of surgeons performed three scoring sessions with the endotower simulator in a maximum time frame for each session of 240 seconds. Table 1 summarizes the mean and standard deviation of the data. Comparisons between the two groups was done with the Student T test. All six randomly placed colored arrows were identified within the allotted time frame 88.9% by the experts and 58.3% of the time by the novices. With the novices, only one run was error free (i.e. no red-outs), while a third of the expert runs were error free.

Table 1: Mean and Standard Deviation of the number of arrows correctly identified and number of errors

	Novices	Experts	P value
Correctly identified Arrows	5.3 ± 1.1	5.9 ± 0.3	0.045
Errors (‘Red-outs’)	3.1 ± 3.1	1.0 ± 0.9	0.023

4. Discussion / Conclusions.

Our endotower laparoscopic navigation simulator has successfully reproduced the optics and movements of a 30 degree angled lens. We are able to portray a realistic view of a three dimensional object as it is navigated with a virtual laparoscope. All of our test users found the graphical user interface to be adequate. The dual pentium personal computer with an OPENGL graphic accelerator provides a system with fast frame rates and the VLI system provides an economical laparoscopic simulator interface with no perceived lag.

More work is needed on the tool handle interface. The Immersion device was designed to portray two laparoscopic instruments and not a lens/camera laparoscope. Our current system has the user using the right instrument as the navigating camera and the left instrument purely for rotation of the scope. Most of our users found this to be somewhat cumbersome. Whereas true angled laparoscope have the camera and lens held in the same hand, we developed our system using the VLI and a two handed technique as an economical alternative. We are currently developing plans to provide a more accurate hardware tools/handles user interface for the simulator.

Initial tests using experienced surgeons and novices to compare scores on the simulator suggest that manipulating a 30 degree laparoscope is a skill that is not intuitive but rather acquired. More errors were made by the novice than the experts. These findings suggest construct validity for the simulator in the scoring system.

Times varied widely in our novice group and may represent the underlying differences in understanding visuospatial relationships. This could suggest that there are subgroups novices that may be more adept at tasks involving visuospatial skills than others.

Ongoing development is focused upon providing users more feedback and adding functions to output and analyze motion metrics [14]. The intent is to provide a method to learn how to efficiently manipulate a laparoscope by measuring surgical skills in a simulator. Future plans include improving the hardware tools/handles interface, adapting the environment to clinical situations, and validating that acquisition of skills using the simulator that will affect performance in live situations.

5. Acknowledgments.

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