Pilot Study: Supplementing Surgical Training for Medical Students Using a Low-Cost Virtual Reality Simulator

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***Abstract*—The goal of this research is to evaluate the benefits of using a low-cost Virtual Reality (VR) surgical training platform in bridging the gap between early surgical skills and effective performance in more advanced training and clinical settings. The specific aim of this study is to design and evaluate the efficacy of a low-cost virtual reality system as a precursor to improving surgical skills for novice trainees. A summary of our VR training system is presented, and training results from three pre-med students and five residents in a medical school are discussed that show preliminary evidence of the efficacy of the system.**

Keywords—virtual reality simulator; multi-modal interface; low-cost simulator; laparoscopic cholecystectomy; haptic surgical simulation

I. INTRODUCTION

There has been a noticeable increase in the use of virtual reality (VR) simulation technology for medical training of clinical practice. Studies have shown evidence that the use of VR in surgical training improves the practicing of surgical skills [1,2], especially for novice trainees. Unfortunately, most available surgical simulators are expensive, with a documented cost ranging between $40K on the low-end to close to $100K [3]. Although there is some evidence showing such simulators can provide the quality of training and testing necessary before a clinical experience for residents, their cost profile makes them unsuitable for use by student populations outside of their training facility.

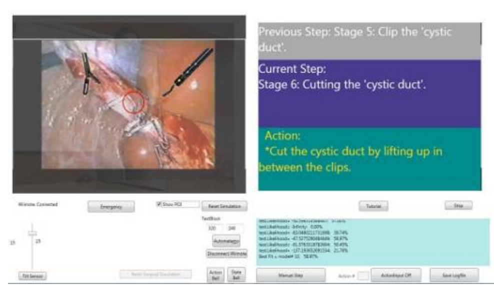
Given the current climate of budget reductions and reduced allocations to aid hospitals to pay for training of new residents and medical students, we shared the urgent need for the development of effective and low-cost training options to fill in the gap. As such, a low-cost VR surgical simulator was developed and presented in [4], as depicted in Fig. 1-(a). As a follow-up study, we evaluated the system with residents and pre-med students (Fig. 1-(b,c)) in terms of the effectiveness of transferring knowledge and skillsets necessary for a surgical practice. In this paper, we present the surgical domain of our simulation, a brief explanation on the purposes of our system, the hypothesis of our project, and methodologies. Lastly, the preliminary results with medical students will be discussed, followed by plans for future research.

II. LAPAROSCOPIC CHOLECYSTECTOMY

Laparoscopic cholecystectomy is one of the most common surgeries currently performed in the United States and is often used as the training case for laparoscopy due to its high frequency and perceived low risk. Since its introduction to surgery in the 1980s, the laparoscopic removal of a diseased gallbladder (laparoscopic cholecystectomy) has become the gold-standard [5]. It is the most commonly performed elective abdominal procedure in the United States. The present instructional method for learning laparoscopic surgery involves an apprenticeship to a senior surgeon. Studies have shown that additional training, beyond the hours of initial guidance, is a necessary component for establishing expertise [6].

III. PURPOSE, HYPOTHESIS, AND METHODS OF RESEARCH

The primary aim of this study is to examine the efficacy of the low-cost VR surgical simulator on improving surgical skills, as a precursor to learning on a robotic surgical simulation. Our hypothesis is that the adherence to a low-cost VR-program will increase the student's skillset, as measured by the student's learning curve.



(a) GUI of our VR Surgical Simulator

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(b) Pre-med student (c) Resident

Fig. 1. Screenshot of our VR surgical simulator (upper image) and the simulator being tested by a premed student and a resident (lower two images).

To examine system efficacy, our research approach analyzes the increase in the level of skill that can be brought to bear on a clinical situation while enabling a mobile and interactive framework composed of low-cost components. To enable simulation of surgical operations, the designed virtual training system must employ the same ergonomics applicable to surgeries while teaching appropriate muscle memory for safe and effective operations.

As such, our VR surgical simulator [4] couples four primary elements for VR-training in laparoscopic cholecystectomy:

1) *VR Environment*: The virtual environment is designed to depict patient-specific anatomy, as well as surgical instrument interaction, during surgical operations. The primary function of the virtual environment is to provide an emulation of the real surgery application that promotes sufficient learning.

2) *Motion Sensors*: In order to employ appropriate muscle memory, the surgical instruments projected within the virtual environment must correlate directly with the user's hand and arm movements. This research uses the Microsoft Kinect, a low-cost 3D depth camera, to turn our VR environment into a virtual operating room.

3) *Haptic Feedback*: In prior work, we have shown that haptic feedback is an important mechanism for transferring motor skills between expert and novice users [7]. Accordingly, our VR system utilizes low-cost haptic feedback devices (Wiimotes) for providing a simulated realization of the surgical tools and for providing feedback during achievement of the surgical operation.

4) *Training*: To evaluate surgical skills and govern overall training, we employ a Hidden-Markov-Model (HMM) approach [8, 9] that enables the computation of a generalized model of expert surgeons' skills. This information is utilized to determine the maximal likelihood of a student's surgical skills matching the expert model.

IV. Experimental Setup

We designed our simulator to display fifteen key stages of a cholecystectomy operation, with each tutorial stage followed by an interactive evaluation phase on the student's actual exercise of the surgical actions in the surgical phase (details are presented in [4]). For the training of HMM modules for the "correct" surgical actions, we extracted motion sequences from two expert surgeons' demonstration while developing the system. The student's actions during the evaluation phase are compared with the experts' actions using the HMM module to determine if the student has taken the correct surgical action. If the actions were correct, the simulator will proceed to the next stage of the surgical operation. However, if the actions are not matched, the simulator would determine that the student is not trained enough and restart the tutorial stage (i.e. playing a video clip for the corresponding surgical stage) followed by the interactive evaluation phase again. The simulator is designed to take only 5~20 minutes total based on the trained level of the student.

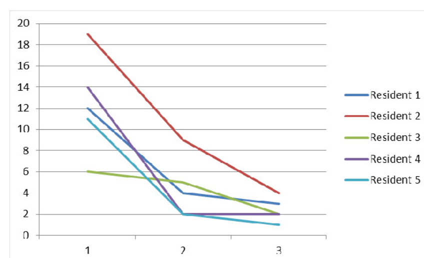
Prior to the first trial of the simulator, the participant (the "student") was given a 5-minute explanation and a demonstration of how to interact with the system. The participant was introduced with the tutorial video on the cholecystectomy (2-minute, with 1~2 replays if requested), and then was allowed to freely engage with the simulator while holding two Wiimotes and standing in front of the simulator facing the computer and the Kinect sensor. Each trial took less than 15 minutes in general, and to reduce memorizing effect the participants are allowed to try the simulator once in a week for three weeks.

To evaluate the performance and effectiveness of our system in the learning of the cholecystectomy operation, we measured and evaluated the following criteria: average number of tutorial video played, and average number of surgical actions taken. All protocols and guidelines for this experiment followed the IRB protocol H11362: VR-in-a-Box: Surgical Simulator.

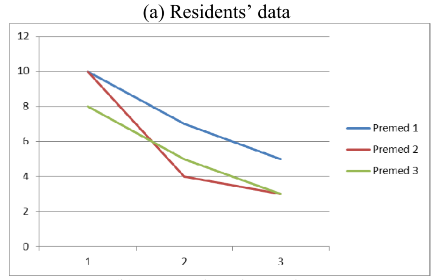
V. Results

A total of eight human subjects—five residents (ages: 29~37) from Morehouse School of Medicine at Grady Memorial Hospital and three pre-med students prior to entering medical schools (ages: 22~24)—participated in our experiments. During their trials on the simulator, the following data was collected: the number of times the tutorial mode was activated and the number of surgical actions initiated during each trial.

The number of activated tutorial mode was observed to evaluate how well the participants understood the operational steps of the surgery. As plotted in Figure 2, the subjects initially exhibited a high number of tutorial mode activations, correlating with incomplete knowledge on the surgical operations using the simulator and its interface on the first trial.



(a) Residents' data



(b) Pre-med students' data

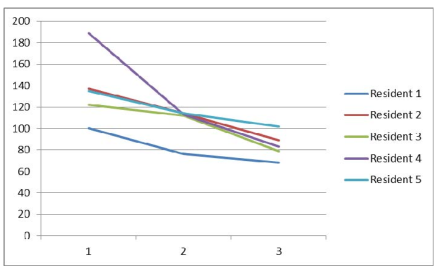
Fig. 2. Results of the number of activated tutorial modes (time-outs due to incorrect movements) over three trials over three weeks.

Table I. Average number of tutorial modes activated during simulation (STD=standard deviation).

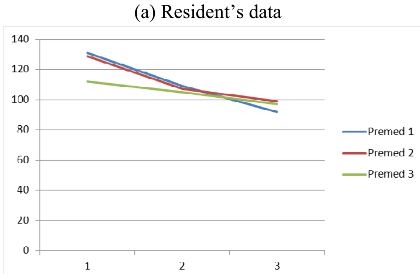
Tutorial modes	Trial 1	Trial 2	Trial 3
	Mean (STD)	Mean (STD)	Mean (STD)
Residents	12.4 (4.72)	4.4 (2.88)	2.4 (1.14)
Pre-meds	9.33 (1.15)	5.33 (1.53)	3.67 (1.15)

However, as shown in Table I, both participating groups showed steep learning curve at the second trial (64.5% decrease in average in the residents group and 42.9% decrease in average in the premeds group), and after the third trial both group displayed rapid decrease in the number of tutorial modes by 80.6% (residents) and 60.7% (premeds).

The number of surgical actions taken per simulation was recorded to analyze how accurately the participants learned the skills needed to complete the cholecystectomy simulation (as displayed in Fig. 3 and Table II).



(a) Resident's data



(b) Pre-med students' data

Fig. 3. Results of the number of actions taken over the whole simulation over three trials over three weeks.

Table II. Average number of surgical actions taken per simulation (STD=standard deviation).

Surgical Actions	Trial 1	Trial 2	Trial 3
	Mean (STD)	Mean (STD)	Mean (STD)
Residents	136.6 (32.79)	105.8 (16.68)	84.2 (12.56)
Pre-meds	124 (10.44)	107 (2.00)	96 (3.61)

Similar to the case of the number of tutorial modes, the pre-med students showed quick adaptation to the system at the first trial (showing less number of tutorial mode activations and surgical actions than the residents). After three trials, the residents showed 38.4% decrease in the total number of actions and the pre-med students displayed 22.6% decrease in number of actions taken. Considering the fact that the minimal number of actions required to finish the simulation is 70, we argue that the residents showed well-equipped knowledge and trained skillsets on the cholecystectomy operation. Further, we could observe from the pre-med students' results that with only three trials of the simulation (total of 45minutes~1 hour of simulation time), the students were effectively learning the knowledge and skills required to perform the operation with the rate of approximately 58.8%~75.3% of the learning curve of the residents.

VI. CONCLUSION

The primary objective of this research was to evaluate a low-cost VR system that could function as a training system for students outside of the hospital training facility. Supposing that most students possess computing platforms these days, the resulting cost of the system totals $300 in peripherals (Kinect for Windows and Wiimotes). By comparing the learning effect on novices (pre-med students) and near-expert users (residents), we have preliminary results that show the VR surgical simulator not only reduces errors in the actions but decreases the overall number of surgical actions required for completing the operation. Future research efforts include developing haptic sensing and feedback system for acquiring and displaying actual force profile during the surgery and more rigorous statistical analysis of the data.

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REFERENCES

[1] J.A. da Cruz et. al., "Does Training Laparoscopic Skills in a Virtual Reality Simulator Improve Surgical Performance?" *Journal of Endourology,* 24(11): 1845-1849, Nov. 2010.

[2] N.E. Seymour et. al., "Virtual Reality Training Improves Operating Room Performance Results of a Randomized, Double-Blinded Study," *Annals of surgery*, 236(4): 458–464, October 2002.

[3] B. Dunkin, G. Adrales, and K. Apelgren, J. Mellinger, "Surgical simulation: a current review," *Surgical Endoscopy*, 21: 357-366, 2007.

[4] C.H. Park, K. Wilson, and A.M. Howard, "Examining the Learning Effects of a Low-Cost Haptic-Based Virtual Reality Simulator on Laparoscopic Cholecystectomy," *Proceedings of CBMS 2013: 26th International Symposium on Computer-Based Medical Systems*, pp. 233-238, 2013.

[5] N.J. Soper, P.T. Stockmann, and D.L. Dunnegan, S.W. Ashley, "Laparoscopic cholecystectomy: The new 'gold standard'?" *Archives Surgery*, 127 (8): 917–21, August 1992.

[6] V.C. Gibbs and A.D. Auerbach, "Learning curves for new procedures. The case of laparoscopic cholecystectomy," *Making Health Care Safer: A Critical Analysis of Patient Safety Practices, Evidence Reports / Technology Assessments*, No. 43, 2001.

[7] C.H. Park and A.M. Howard, "Transfer of Robotic Tele-operation Skills between Human Operators through Haptic Training with Robot Coordination," *Proceedings of IEEE Int. Conf. on Robotics and Automation (ICRA)*, Anchorage, May 2010.

[8] L.E. Baum and T. Petrie, "Statistical Inference for Probabilistic Functions of Finite State Markov Chains," *The Annals of Mathematical Statistics*, 37 (6): 1554–1563, 1966.

[9] T. Starner and P. Alex "Real-Time American Sign Language Visual Recognition From Video Using Hidden Markov Models," Master's Thesis, MIT Program in Media Arts, February 1995.