# Telementoring System Assessment Integrated with Laparoscopic Surgical Simulators


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***Abstract*—Laparoscopic simulators have emerged as effective tools for surgical training. The virtual environment is used in the simulator for the training of procedure-specific surgical skills. These simulators can be enhanced if an expert can provide guidance on every surgical step of the procedure, as well as provide feedback as each step is performed by the trainee. In pursuit of this objective, this study introduces a telementoring system designed to be seamlessly integrated with surgical simulators, thereby enabling remote training. The system incorporates guidance from an expert located remotely, utilizing audio-visual cues as a means of instruction. The visual cues consist of the virtual laparoscopic instruments, which is remote-controlled by the expert and superimposed onto the operative field displayed on the simulator's visualization screen. The system was evaluated for its technical performance, and a user study was conducted. The technical evaluation showed low latency to enable real-time communication, whereas the user study demonstrated effective transfer of surgical skills.**



***Keywords—Telemedicine, Surgical Tele-mentoring, Surgical Simulators, Laparoscopy, Virtual Reality***


## I. INTRODUCTION

The field of surgery has undergone an evolution since the widespread adoption of laparoscopic surgery [1]. However, training of laparoscopic surgeons necessitates acquiring skills that are difficult to master due to limited visual acuity, challenging hand-eye coordination, and dependence on haptic sensorimotor skills [2]. Due to the steep learning curve, potential risk to patients, and fluctuating effectiveness of different surgical procedures, the trainee-tutor model in surgical training [3] has been deprecated and transitioned into a variety of simulated training methods [4]. Today, box trainers and computer simulators using Virtual Reality (VR) have become common methods of acquiring the surgical skills essential in laparoscopic surgery [5].

The COVID-19 global pandemic has raised concerns about the conventional methods of training due to restrictions on travel leading to a shortage of experts and reduced resident exposure to patient volume and educational activities [6]. In such a scenario, an adaptation of remote training integrated with surgical simulators can aid to overcome the aforementioned challenges during surgical training. While the existing surgical telementoring technologies include the transfer of audio and visual cues (such as screen markings [7] and hand gestures [8] augmented onto operative field view), they lack the details to show the required tool-tissue interaction. In this work, a telementoring framework is proposed that facilitates remote training on a surgical simulator. The expert can guide by demonstrating the necessary interaction of the tool with the tissue in every step of the simulated surgical procedure. As the trainee performs the procedure, the expert provides feedback to the trainee on the execution of each step.

## II. MATERIALS AND METHODS

In this work, the proposed remote telementoring system was developed based on the framework established in our prior research [9]. The framework facilitates remote surgical training through the exchange of audio and visual cues between expert and trainee. The visual cues comprised of virtual laparoscopic instrument's motion (remotely controlled by an expert surgeon) superimposed onto the surgical field video allowing the demonstration of precise tool-tip movements. The following subsections describe the integration of the surgical simulator for remote guidance during laparoscopic training.

### *A. Structure of System*

The developed telementoring system comprises two workstations, one in a training room and the other in a remote place. These workstations are interconnected in the network, as shown in Fig. 1 and described as follows.

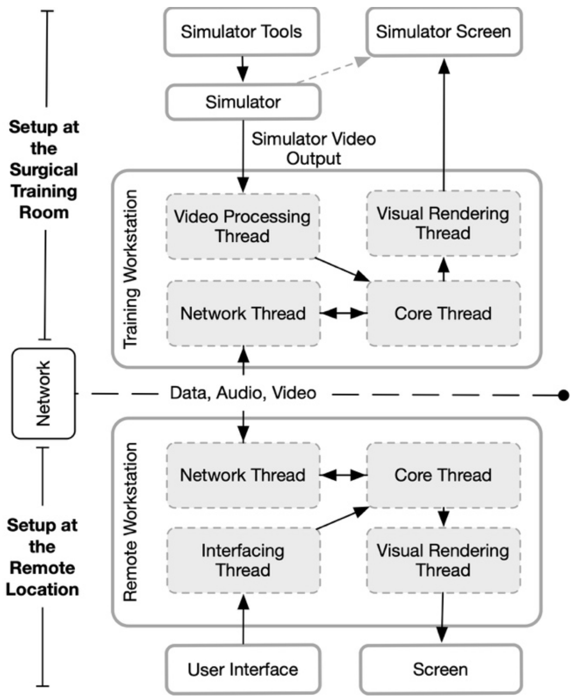


Fig. 1. Structure of tele-mentoring system in this study.

*1) Setup at Surgical Training Room:* At the surgical training room, the trainee interacts with a simulator connected to the training workstation (Fig. 2). The video output from the simulator is bypassed to the video processing thread of the training workstation, which otherwise is displayed on the simulator screen. The video processing thread then transfers each frame to the core thread. The core thread of the work- station initiates and coordinates calls to all other threads. It allows the definition of tool incision points and passes the data to the visual rendering thread, where virtual surgical tools are rendered onto the simulation video frames. These augmented video frames are then projected directly onto the simulator's screen. The network thread is responsible for transferring audio, video, and tool data between the two workstations over the network. The network transfer used the WebRTC protocol for the transfer of the surgical video and corresponding data, comprising of incision points and virtual tool-tip poses [9], [10]. To record the tool and scope incision points from the simulator, a V120:Trio optical tracking system is used. Inside the workstation's core thread, the incision points' positions are recorded and defined.

*2) Setup at Remote Location:* At this location, an expert surgeon guides the trainee using the remote workstation. The network thread receives video and data from the training workstation are transfers it to the core thread (where incision points for the tools are defined and relayed to the visual rendering thread). The augmented surgical tools are then rendered over the received surgical video. A user-interface device is used by the expert to control the augmented surgical tools' motion [11]. Poses of the tooltips are handled by the interfacing thread and sent back to the training workstation by the networking thread, using the WebRTC protocol. The motion of the tools is then reconstructed and augmented onto the surgical video in the training room. Displaying these movements on the simulator screen forms visual cues that guide the trainee in laparoscopic training on the simulator (Fig. 3).

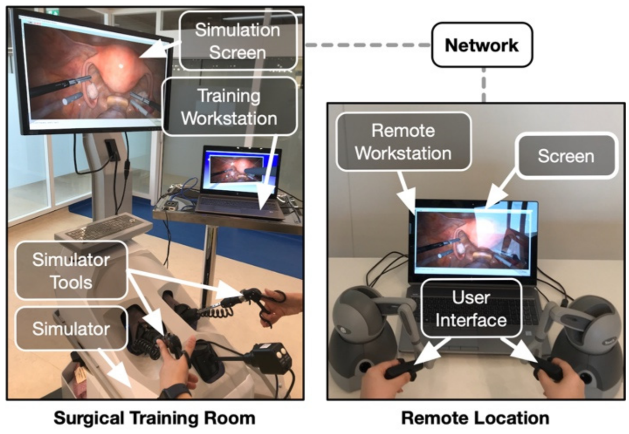


Fig. 2. Tele-mentoring system integrated with a surgical simulator.

## B. Experimental Setup to Evaluate Technical Performance

The system was integrated with a surgical simulator (LapVR$^{TM}$ laparoscopic simulator by CAE Healthcare). Geomagic Touch$^{TM}$ by 3D Systems was used as a user-interface device at the remote location. To assess the technical performance of the system, evaluations were conducted in both intra-country and inter-country scenarios. In the testing of intra-country scenarios, two different places were situated in Doha, Qatar. In the test of the inter-country scenario, the training room was in Doha, and the remote place was in Houston, the USA. In the experiment, the time of workstations in the two locations was synchronized using a common Network Time Protocol (NTP) server. The data were transmitted over the network to be recorded and evaluated for the proposed system's performance. Each scenario was repeated nine times for comprehensive analysis. The parameters evaluated were: (1) average duration for data transfer, (2) that for receiving two consecutive data packets, (3) dropped data packets, and (4) distortion of video frames over the network.

## C. User Study

The usability of the proposed telementoring system was assessed for remote training on a simulator. It compared two modes of training: Mode-I where an expert was remotely located, versus Mode-II, where an expert was in the same room as the trainee. The laparoscopic training simulation of Salpingectomy was chosen, which involved the withdrawal of the entire Fallopian tube affected by an Ectopic Pregnancy. For each mode, a user study was conducted with 12 subjects (trainees). Each subject was required to complete the procedure twice: first, along with guidance from the trainer (learning stage), and second, without any guidance (testing stage). The surgical simulator generated a report after training, assessing trainees' performances. The parameters evaluated were: (1) complication percentage, calculated from trainee errors over total possible errors in the report, (2) final duration to complete the procedure, and (3) good technique percentage, calculated from successful good techniques practiced by the trainee over all possible good techniques to have followed.

# III. Results and Discussion

Table I provides a summary of the telementoring system's performance. The operative field's video frame size was set to 640 X 480 pixels during network transfer. The average delay in transferring information between the training room and the remote place was higher for the inter-country transfer (due to the large geographical separation). The delays observed in the telementoring system were found to be within the recommended limit of 450 milliseconds, as suggested by SAGES [12]. The data transfer delay and average latency in receiving two consecutive packets at both ends were low. In addition, the negligible amount of dropped frames ensured that the trainer received an uninterrupted and uniform live stream of the training procedure and could immediately respond to any complications that required guidance. Standard video quality metrics, namely mean squared error (MSE), peak signal-to-noise ratio (PSNR), and structural similarity index (SSIM), were employed to evaluate the distortion of video frames resulting in decoding and encoding through the network. It should be noted that MSE and PSNR may not effectively differentiate the structural content when compared to SSIM. Furthermore, SSIM is more closely correlated with the perception of the quality of the human visual system. This is because SSIM takes into account not only structural modeling of image distortion but also factors such as luminance and contrast, which are significant for the human visual system's perception of quality [13], [14].

Table II summarizes the user study result. The complication percentage is for the number of complications during a procedure (for example bleeding and injury to vital structures) out of the total possible complications. During the learning stage, the average complication percentage for Mode-II (remote training) was lower than that of Mode-I (in-person training). However, the decrease from the learning to the testing stage was higher for Mode-I than for Mode II. This meant that training in Mode-II could guide trainees better in real-time minimizing complications, but Mode-I helped trainees learn and understand better. The duration to complete the procedure by trainees remained the same during both stages under Mode-I of training. Whereas, a higher duration under the learning stage of Mode II is reduced to a lower duration in its testing stage. This indicated that the training received under Mode II could help ease the complexity of a procedure, resulting in faster completion of the same procedure when there is no guidance from a mentor.

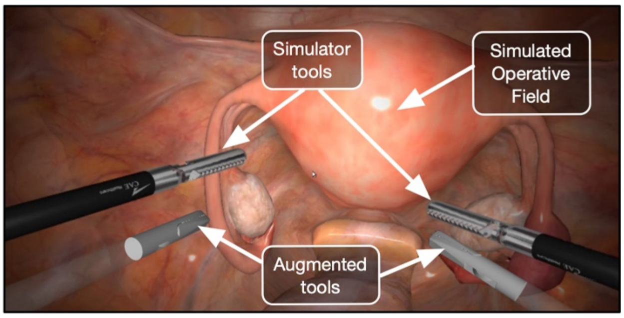


Fig. 3. Simulated operative field view and overlaid augmented tools controlled by the expert remotely.

The integration of the telementoring system with surgical simulators enables real-time guidance, allowing for timely and interactive support. Guidance is provided through audio and visual cues. The visual cues appear as overlaid virtual tools on the visualization screen of the surgical simulator. Guidance through the telementoring system resulted in reduced procedure complications and helped trainees recall instructions faster, as compared to in-person training. The technical evaluation of the system exhibited a reduced latency which ensured synchronization between the transferred information. Additionally, the usability study measured the effectiveness of the capability of data transfer. While the system was designed taking into consideration laparoscopic surgery, it can be extended to simulations for robot-assisted minimally invasive surgeries [15], [16], scope navigation [17], [18], and image-guided interventions [19], [20].

TABLE I. TECHNICAL EVALUATION OF TELEMENTORING SYSTEM

| Parameters | Intra-country | Inter-country |
|---|---|---|
| Average delay in transfer of the data packets to the remote place from the training room | 78 ± 7 ms | 163 ± 12 ms |
| Average delay in two consecutive data packet reception to the remote place from the training room | 33 ± 27 ms | 33 ± 6 ms |
| Percentage of frames dropped during transfer | 0% | 0.59% |
| Average delay in transfer of the data packets to the training room from the remote place | 21 ± 2 ms | 132 ± 23 ms |
| Average delay data packet received from the remote place to the training room | 26 ± 15 ms | 33 ± 8 ms |
| MSE | 242.67 | 245.02 |
| PSNR | 24.28 | 24.25 |
| SSIM | 0.93 | 0.93 |

TABLE II. USER STUDY RESULT USING PROPOSED TELEMENTORING SYSTEM

| Parameters | Mode-I | | Mode-II | |
|---|---|---|---|---|
| | Learning | Testing | Learning | Testing |
| Average complication percentage | 17% | 6% | 11% | 8% |
| Average duration | 12 min | 12 min | 15 min | 13 min |
| Average good technique percentage | 100% | 100% | 100% | 100% |

While the work demonstrated the feasibility of integrating a tele-mentoring system with a surgical simulator, additional end-user studies would be required to measure the effect on the acquisition of scenario-specific surgical skills [21]–[23]. A limitation of the system is that the evaluation was conducted on low resolutions of surgical video frames. Any increase could interrupt the currently harmonious transfer of frames during telementoring and needs further testing. A limitation of the end-user study was that all the remote mentors utilized the Touch™ haptic device as the user-interface device for manipulating the virtual tools. Any differences that may result from the usage of other devices are not assessed in the study. As a next step, we plan to explore the inclusion of virtual guidance contours [24], [25] for guiding surgical instrument motion instead of augmented surgical tools.

## IV. CONCLUSION

The proposed telementoring system enables remote guidance during surgical training on a simulator. An expert at the remote location manipulates virtual tools that are overlaid onto the simulator's visualization screen. These virtual tools form visual cues, along with audio and surgical video exchanged over the network at low latency. The system enables a geo- graphically distant trainee to easily grasp real-time instructions and recall them well in the absence of a mentor.

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