AWARD NUMBER: W81XWH-14-1-0042

TITLE: See-What-I-Do: Increasing mentor and trainee sense of co-presence in trauma surgeries with the STAR platform

PRINCIPAL INVESTIGATOR: Juan P Wachs

CONTRACTING ORGANIZATION: Purdue University, 315 N. Grant Street, West Lafayette, 47907, IN

REPORT DATE: Apr-2018

TYPE OF REPORT: Annual Report

PREPARED FOR: U.S. Army Medical Research and Materiel Command
Fort Detrick, Maryland 21702-5012

DISTRIBUTION STATEMENT: Approved for Public Release, Distribution Unlimited

REPORT DOCUMENTATION PAGE	*Form Approved* *OMB No. 0704-0188*

1. REPORT DATE April 2018	**2. REPORT TYPE** Annual	**3. DATES COVERED** 3 Mar 2017 - 2 Mar 2018

4. TITLE AND SUBTITLE See-What-I-Do: Increasing Mentor and Trainee Sense of Co-Presence in Trauma Surgeries with the STAR Platform	**5a. CONTRACT NUMBER**
	5b. GRANT NUMBER W81XWH-14-1-0042
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S) Juan P Wachs	**5d. PROJECT NUMBER**
	5e. TASK NUMBER
Email: jpwachs@purdue.edu	**5f. WORK UNIT NUMBER**
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) . Purdue University West Lafayette, IN 47907	**8. PERFORMING ORGANIZATION REPORT NUMBER**
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) U.S. Army Medical Research and Materiel Command Fort Detrick, Maryland 21702-5012	**10. SPONSOR/MONITOR'S ACRONYM(S)**
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for Public Release; Distribution Unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

Our primary research objectives are to design, implement, and evaluate a working prototype that enables effective telementoring of a trainee surgeon by a remote mentor. This includes (1) a trainee-site subsystem for augmenting the view of the actual surgical field seamlessly by using a transparent display with illustrations of the current and next steps of the procedure, and (2) a mentor-side patient-size interaction platform with a gesture-based interface.

15. SUBJECT TERMS-
None Listed

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON** USAMRMC
a. REPORT U	**b. ABSTRACT** U	**c. THIS PAGE** U	UU	47	**19b. TELEPHONE NUMBER** *(include area code)*

TABLE OF CONTENTS

Page No.

Purpose: Develop a framework that will enable increasing the mentor and trainee sense of co-presence through augmented visualization to facilitate surgical training and performance.

Scope: Optimal trauma treatment integrates different surgical skills not all available in military field hospitals. Telementoring can provide the missing expertise, but current systems require the trainee to shift focus frequently from the operating field to a nearby telestrator, they fail to illustrate the next surgical steps, and they give the mentor an incomplete picture of the ongoing surgery. We are addressing these gaps by developing STAR – System for Telementoring with Augmented Reality.

Major Findings: This year's main focus was the development of a new interface to deliver surgical guidance to local trainees. Instead of relying on a 2D tablet to present the trainee with the mentor-authored instruction, an Augmented Reality Head-Mounted Display (ARHMD) was utilized to display 3D annotations directly in the mentee's FOV, overcoming 2D annotations issues such as occlusion and binocular depth cues degradation. This ARHMD device allows the Trainee System to construct a virtual representation of the space it is in, and anchor virtual annotations to this space, visible only to the mentee wearing the device. Two experiments were conducted to validate this device. The first experiment was conducted at Indianapolis (Indiana), where 20 medical students performed two different telementored tasks on a patient simulator: an anatomical marker placement and a mock abdominal incision. Participants completed the procedure under two telementored conditions: ARHMD and Telestrator. The second experiment was also conducted at Indianapolis, were a total of 14 medical residents and 6 medical students completed a lower-leg fasciotomy on cadaveric specimens under two conditions: with and without telementored guidance using STAR. In both experiments, participants who received telementored guidance with STAR were able to successfully complete the surgical procedures while improving aspects such as accuracy and confidence in their execution.

In addition, a system to visualize the future steps of a specific surgical procedure was implemented and validated using the tablet-based Trainee System. A set of videos are pre-recorded and stored in a knowledge base before use, in which an expert user performs a procedure on a patient simulator or on a cadaver. The videos show each stage of the operation, including the position of the expert's hands and any surgical instruments.

The trainee can then use the tablet system to visualize and select each pre-generated video clip from the knowledge base to be automatically overlaid onto the live video frames of the trainee's operating field. The video clips appear as semi-transparent overlays on the tablet screen, allowing trainees to view their own hands and surgical instruments and also those of the expert mentor as the expert performs that step of the procedure. To validate this feature, we conducted a study in which 20 participants performed tasks under telementored guidance with an unstable connection. Participants were tasked with completing a cricothyroidotomy on a patient simulator under either conventional telestrator-based telementoring, or telementoring using STAR’s future steps visualization feature. The results indicated that a future step visualization is an important fallback mechanism in surgical telementoring when trainee/mentor network connection is poor, and it is a key step towards semi-autonomous and then completely mentor-free medical assistance systems. Finally, during this year, we started the implementation of an extension of the STAR platform to provide assistance during emergency scenarios in rural environments via a drone-mounted camera. Initial developments include the live broadcasting of the imagery acquired by the drone to the Mentor System interaction table.

1. INTRODUCTION:

Our primary research objectives are to design, implement, and evaluate a working prototype that enables effective telementoring of a trainee surgeon by a remote mentor. This includes (1) a trainee-site subsystem for augmenting the view of the actual surgical field seamlessly by using a transparent display with illustrations of the current and next steps of the procedure, and (2) a mentor-side patient-size interaction platform with a gesture-based interface.

2. KEYWORDS:

Augmented reality, telementoring, telemedicine, computer vision, future-steps visualization, surgical training, co-presence, simulation, tele-existence.

3. ACCOMPLISHMENTS:

The PI is reminded that the recipient organization is required to obtain prior written approval from the awarding agency Grants Officer whenever there are significant changes in the project or its direction.

What were the major goals of the project?

List the major goals of the project as stated in the approved SOW. If the application listed milestones/target dates for important activities or phases of the project, identify these dates and show actual completion dates or the percentage of completion.

Specific Aim 3:
- **STAR specialization for cric in austere environments (03-Set-2017– 03-Mar-2018) 5%**
- **Experimental Design 4: austere environment validation (03-Mar-2018– 03-Mar-2019) 5%**

Specific Aim 4:
- **STAR specialization for fasciotomies on cadaveric legs (03-Mar-2017 – 03-Set-2017) 100%**
- **Experimental Design 5: Validate STAR in fasciotomies (03-Mar-2017 – 03-Mar-2018) 95%**

What was accomplished under these goals?

For this reporting period describe: 1) major activities; 2) specific objectives; 3) significant results or key outcomes, including major findings, developments, or conclusions (both positive and negative); and/or 4) other achievements. Include a discussion of stated goals not met. Description shall include pertinent data and graphs in sufficient detail to explain any significant results achieved. A succinct description of the methodology used shall be provided. As the project progresses to completion, the emphasis in reporting in this section should shift from reporting activities to reporting accomplishments.

***Major Activities:* Research, develop, and assess a transparent-display augmented-reality system that allows the seamless enhancement of a trainee surgeon's natural view of the surgical field with annotations and illustrations of the current and next steps of the surgical procedure.**

Specific Objectives

Task 3.1- Specialize the system for a cric procedure on a patient simulator in an austere environment

Implementation of a head-mounted, augmented reality telementoring platform

In the previous annual report, we introduced the concept of implementing the Trainee System with an ARHMD (Microsoft HoloLens). An augmented reality telementoring system that uses a head-mounted display at the trainee side possesses two main advantages over our existing tablet-based system. First, the ARHMD see-through feature allows trainees to see the surgical field directly, as if they were looking through glasses. The virtual annotations are displayed to the trainee with slightly different images for each eye, such that the trainee user perceives the annotation as being located in 3D space on the patient's body. This is in contrast to the tablet-based approach, which can only deliver a single image of the operating field to the trainee, and thus remove the trainee's depth perception, which is needed for quick and accurate actions in the operating field. In previous evaluations of the tablet-based trainee system, we found that users showed a large amount of hesitancy and delay when performing precise tasks. When the tablet physically occluded their hands, trainee users had to slowly move their hands into the correct location and depth to interact with the operating field. Second, a head-mounted display means that the trainee's hands can move freely around the operating area without concern of colliding with a tablet suspended over the patient's body. Such collisions could lead to misalignment of mentor-provided annotations, delays in providing adequate surgical care, and obstruction of the tablet screen due to blood or other fluids from the patient's body.

The ARHMD has the ability to create a low-resolution 3D representation of the space it is in, and allows 3D models to be placed in this space, visible only to the user wearing the device. shows an overview of the ARHMD based telementoring system. On the mentee side (Figure 1, *left*), a camera captures the overhead of the operating field, which is them stream to the Mentor System. The video stream is transmitted using the WebRTC protocol, which adaptively changes bitrate and resolution. This adaptive streaming ensures that the video is as low latency as possible, which is important for communication between mentor and trainee in bandwidth-constrained environments. The overhead feed is displayed on a full-size patient touch-based interaction table (Figure 1, *right*). The interaction table allows the mentor to annotate the surgical field with gestures. The annotations are sent back to the mentee site where they are integrated into mentee's view of the surgical field using an ARHMD worn by the mentee. The annotations are converted from 2D to 3D by projection from the overhead camera view, where they were authored, to the 3D geometry of the surgical field acquired by the ARHMD. This way the remote mentor can annotate the surgical field in real time, and the annotations are shown to the mentee with correct depth perception, anchored to the surgical field entities that they describe.

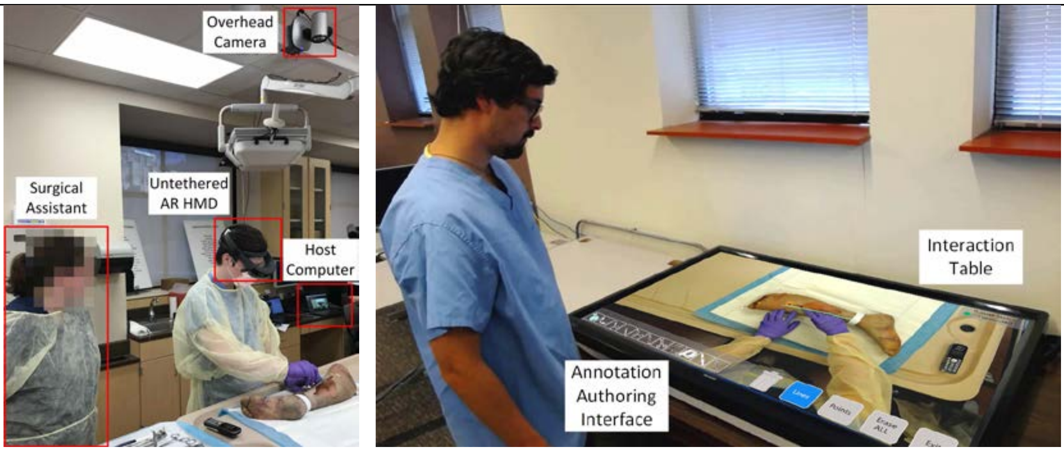


Figure 1: Our telementoring system based on an ARHMD at the mentee and on a full-size touch-based interaction table at the mentor. Mentee subsystem (left) and mentor subsystem (right).

Figure 2 shows an overview of the architecture of the ARHMD-based telementoring system. The untethered, self-tracking ARHMD used in our telementoring system provides the position and orientation of the HMD with respect to the world. Nonetheless, this change of system architecture entailed several challenges. In our early tests involving video streaming from the ARHMD, we encountered two issues with sending first-person video from the ARHMD on-board camera to the remote mentor. First, because the position and orientation of the ARHMD relative to the operating field changes as the trainee moves their head around, it is difficult to adequately align mentor-provided annotations into the correct frame of reference such that the annotations appear anchored to the operating field. Second, the view from a first-person video view is more unstable and confusing for a mentor; a mentor would need to tell a trainee to keep their head still while the mentor creates an annotation, which would interfere with normal operation. For these reasons and as described before, we decided in this iteration of STAR to introduce an additional camera that would capture the operating field from a stationary position. Above the operating field, we attach a high-resolution camera (which we call the top-down camera) from a tripod or from the ceiling. The top-down camera is connected to a small laptop computer located at the trainee site, which transmits video from the top-down camera to the remote mentor wirelessly.

Precisely aligning the coordinate system of the top-down camera with the ARHMD system is essential. This alignment is done by performing a one-time initial calibration process: by introducing a chessboard, the relative position and rotation to it of both the top-down camera and the ARHMD are obtained via computer vision techniques. The goal of the calibration stage is to determine the pose from the overhead camera in the ARHMD’s coordinate: a successful camera calibration is required for the system to convert the mentor's 2D annotation points into 3D rays extending from the center of the camera into operating field.

Figure 3 shows a screenshot of our calibration process. Before use by the mentor and trainee, we use a checkerboard pattern to calibrate the top-down camera. The system uses computer vision algorithms to detect the 2D image locations of each corner on the chessboard. After a series of samples have been captured (about 30 images), we use the data to find the intrinsic parameters of the camera. The camera intrinsic parameters are saved to file. This intrinsic calibration is invariant to any camera motion, and so only needs to be computed once for a particular physical camera that is being used as the top-down camera.

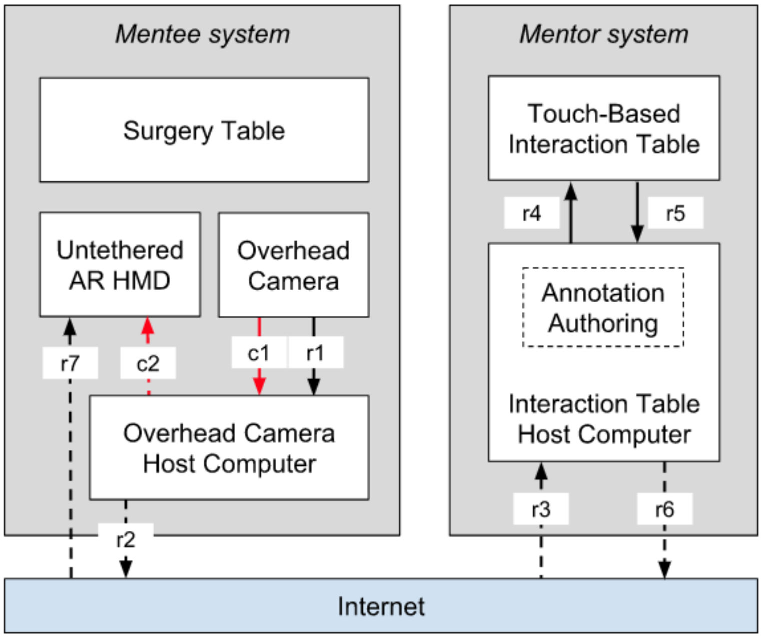
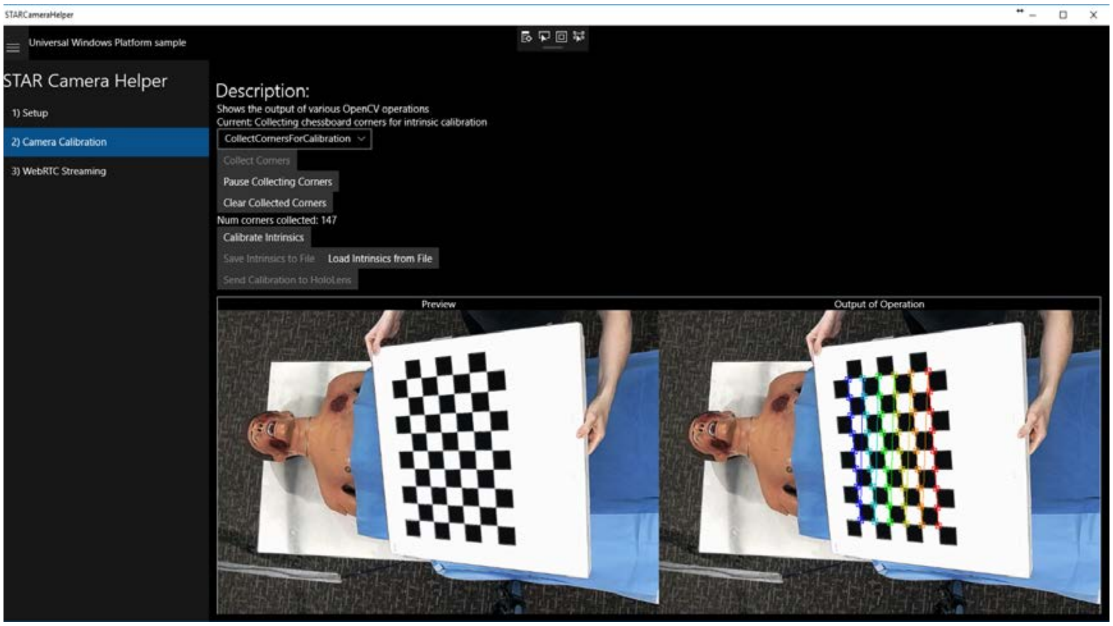


Figure 2: System diagram. Solid and dotted arrows correspond to wired and wireless communication, respectively. Red illustrates system calibration, and black illustrates system operation.

The overhead camera sends its image to the host computer (Figure 2, *c1*), where the checker corners are detected and the overhead camera's pose relative to the checkerboard is recovered by solving a perspective-n-point problem. The pose of the ARHMD relative to the checkerboard is computed similarly. The overhead camera's pose is then sent to the ARHMD (*c2*), where the final pose of the overhead camera relative to ARHMD's world coordinates is computed, and used to during operation to visualize the mentor's annotations.



Description:
Shows the output of various OpenCV operations
Current: Collecting chessboard corners for intrinsic calibration

Num corners collected: 147

Figure 3: Screenshot of our helper application to calibrate the top-down camera at the trainee site.

The overhead camera captures a live video feed of the surgical field (*r1*), which is sent to the remote mentor via the Internet (*r2*). The feed is received at the mentor subsystem (*r3*), where it is displayed on the touch-based interaction table (*r4*). The mentor examines the surgical field, zooms in (digitally) and pans the view, and authors annotations as needed using touch-based gestures. The annotation authoring commands are collected (*r5*) and sent to the mentee subsystem via the Internet (*r6*). The ARHMD is connected to the Internet and directly receives the annotation commands (*r7*), which it uses to show the annotations to the mentee in 3D.

Since the mentor authored the annotations in 2D, these annotations need to be converted to 3D annotations suitable for stereo ARHMD visualization. Annotations have to be anchored to the surgical field entities that they describe. For example, an incision line has to be drawn at the correct depth such that it appears to actually touch the patient surface. All annotations have one or more points of contact with the surgical field geometry. Given a 2D annotation point in the overhead camera image plane, its 3D position in the world coordinates is computed by intersecting the un-projection ray from the overhead camera with the surgical field geometry, acquired by ARHMD. Figure 4 shows and artist rendition of the rays obtained after a success calibration procedure between the ARHMD and top-down camera.

Figure 4: Calibration stage (left): the overhead camera (green ray visualization) is registered with respect to the ARHMD built-in camera (red rays) using a calibration checkerboard. Operation stage (right): The incision line, the scalpel tip, and the textual label stem tip are projected from the overhead camera's perspective onto the surgical field geometry. The incision line lies on the patient, whereas the scalpel and the label annotations float above the patient.

Evaluation of a head-mounted, augmented reality telementoring platform

In this section, we describe an experiment conducted in order to evaluate the effectiveness of an augmented reality head-mounted display for the trainee component of STAR. We first give some background into the motivations behind the use of head-mounted displays in the operating room. Second, we describe the experiment we conducted and the metrics we captured. Third, we offer the results of our experiment. Finally, we provide a discussion and analysis of the results, concluding that the use of head-mounted displays at the trainee side in surgical telementoring is useful for increasing accuracy, reducing encumbrance, and reducing focus shifts.

This experiment was intended as an initial validation of ARHMDs as viable devices for surgical telementoring. A pilot application that allowed for proof-of-concept testing of the ARHMD was developed. In this pilot application, a set of pre-generated graphical annotations could be shown to a trainee user in the context of two specific tasks: a surgical port placement task, and an abdominal incision task. For each task, a user could view instructions in the form of lines, circles, and 3D models of surgical instruments that were superimposed onto a patient simulator. We used this pilot application for the purposes of the experiment described here. Figure 5 displays a participant wearing the ARHMD while performing the experiment, while Figure 6 portraits an example of one of the instructions provided by the pilot application.

Figure 5. STAR platform ARHMD-based Trainee System

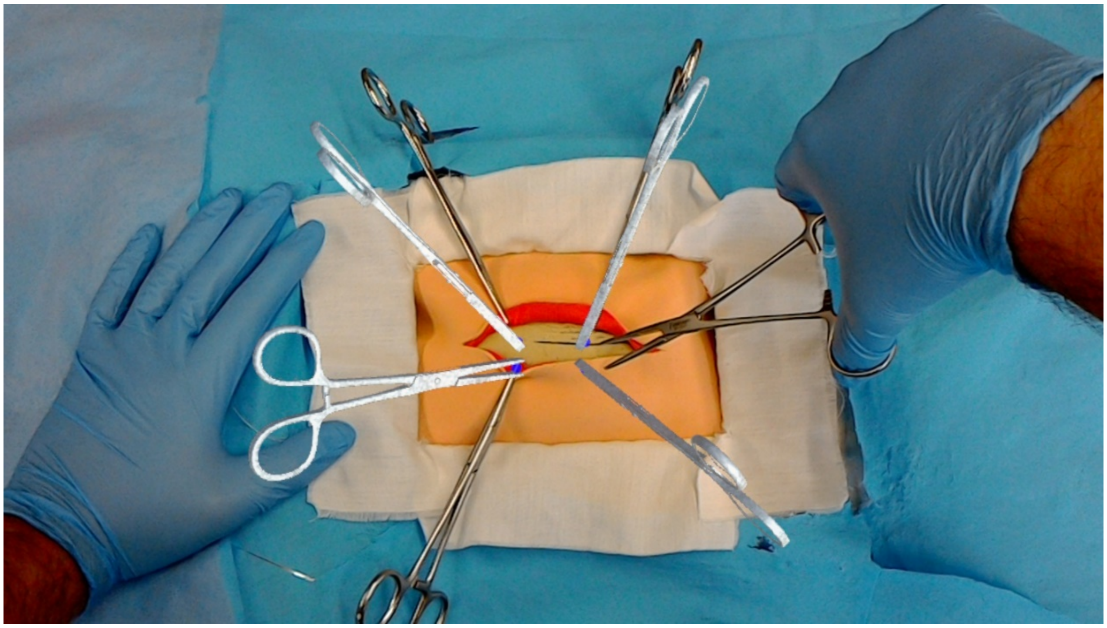


Figure 6. First person view of the STAR ARHMD pilot application

Twenty medical students (14 male, 6 female) from Eskenazi Hospital were recruited. The age of the participants ranged between 23 and 29 years old, and they were in their second, third, or fourth year of medical school. None of the participants had previous experience with surgical telementoring systems. The study was reviewed and approved by Indiana University Institutional Review Board, and written participant consent was acquired for each participant prior to the study. The participants were randomly assigned into one of two groups (the STAR condition and the telestrator condition). Participants in the STAR condition performed a set of simulated surgical procedures while receiving mentor guidance via an ARHMD that rendered graphical annotations directly onto the participant's view of the operating field. Participants in the telestrator condition performed the same procedures, but instead received mentor guidance by looking at a nearby monitor.

The experiment consisted of two tasks that were performed by each participant: a marker placement task and an abdominal incision task. The marker placement task was repeated three times while the abdominal incision task only had a single trial. In the marker placement task, participants received indications sent by the mentor to mark different locations of the patient simulator's body (around the neck and chest) with a dry erase marker. In each of the three trials for this task, different locations were indicated and in a different sequence, in order to avoid recall. After each trial, the marks made by the participant were cleaned off the patient simulator. In the abdominal incision task, the participants used surgical instruments (scalpel, retractor, scissors, and hemostats) to cut through two simulated layers of skin and to spread the linea alba. Each step of this incision procedure was guided by a graphical annotation from the mentor. In addition to the instruments, a felt-tipped marker was also given to the participants: they were required to mark on the patient simulator the place where surgical instruments or their incisions would be used prior to their use.

Figure 7 shows a diagram of the setting used for our experiment. A patient simulator was placed on an operating table, with the study participant acting as a trainee. In the STAR condition, participants wore an ARHMD that displayed remote mentor annotations, while in the telestrator condition, participants looked at a monitor placed 60° to the patient's right side in order to view mentor instructions.

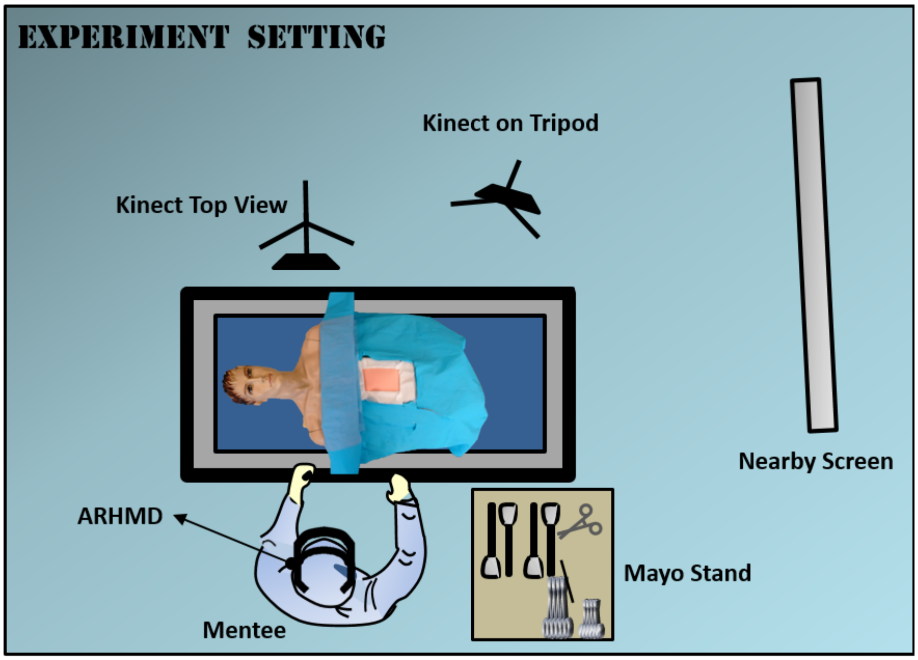


Figure 7. Experimental setup for STAR ARHMD experiment

A between-subjects design was selected, with the telementoring conditions (telestrator and STAR) as the independent variable. We measured four selected metrics as dependent variables: placement error, task completion time, focus shifts, and potential tablet collisions avoided. We also provided a questionnaire to subjects at the end of the procedures to assess system usability.

- **Placement error:** In each trial of each task, participants made a series of marks on the patient simulator. We measured placement error by computing the average 3D Euclidean distance between the location on the patient simulator that was indicated by the mentor annotation, and the location on the patient simulator that the participant actually marked. Using a previously developed annotation-measuring tool, we transformed the points as measured by an overhead depth camera into a common 3D coordinate system to measure the placement error.
- **Task completion time:** For each of the tasks, the time taken to complete the task was obtained for each trial for each subject. Time was measured in seconds.
- **Focus shifts:** Using video recordings for each of the tasks and trials, we measured the number of times a participant shifted focus away from the operating field while completing a single trial. A focus shift was defined as a noticeable change in head orientation outside of the operating field area. In this sense, looking for the next tool needed for the abdominal incision on the mayo stand was not considered a focus shift, since the task demanded the change of tool. Focus shifts were determined as an absolute value per participant per trial.
- **Workspace efficiency:** To compare the actions of the participants against a hypothetical scenario in which participants used a tablet-based system, we recorded Kinect data that captured the pose of the participants' arms and upper body. We then calculated the trajectory of the participant's arms while completing each task. In later analysis, we compared the arm trajectory against the 3D location of where a tablet would have been placed in our original tablet-based system. We counted the number of times that a participant would have collided with the tablet, and how long they would have been collided, by measuring the intersection of the arms with the 3D rectangle representing the tablet's position.
- **Questionnaire:** After participants completed each of the two tasks, they completed a written questionnaire, which asked a series of questions about the perceived usability of the system they used.

We found that participants using the ARHMD had lower placement error, fewer focus shifts, and had a more favorable opinion of the system in questionnaires; however, such participants did take longer to complete the tasks than participants using the conventional telestrator system. The results are summarized and explained:

- **Placement error:** For the marker placement task, participants using the STAR condition (μ, 11.37mm; σx, 0.72mm) reduced their placement error by 9.36 mm on average when compared with those using the conventional telestrator condition (μ, 20.73mm; σx, 5.11mm), which represents an improvement of 45% ($P < 0.001$). In a similar manner for the abdominal incision task, participants using STAR (μ, 8.606mm; σx, 0.806mm) reduced their average placement error by 1.344mm when compared with the ones that used the telestrator (μ, 9.95; σx, 1.07mm); an improvement of 14% ($P = 0.010$). The normality assumption was preserved by discarding the values associated with the participants that presented the highest placement error (outliers) in both the STAR and the telestrator conditions (one outlier per condition).

Participants using the HMD STAR platform significantly reduced their placement error when compared to those using the conventional telestrator condition. The instructional imagery in the HMD STAR platform was overlaid directly into the field of view of the trainee; participants did not have to shift their focus to receive these instructions. In contrast, participants using the telestrator condition had to shift their focus constantly to observe and memorize the annotations' position before replicating them in the body of the patient, which led to an increased cognitive load demanded by the task.

One major advantage that the STAR platform has is the intrinsic 3D visualization. The images displayed in the telestrator condition are in a flat, 2D plane. Although this conveys a general notion of where the annotations should be placed, it fails to transmit where in the body's contour the annotation should be placed. In contrast, the STAR platform places annotations in the 3D space of the device users: a more natural mapping between the annotation's source and the patient's body translated in a more accurate placement of the annotation.

- **Task completion time:** The average time taken that participants using the STAR platform (median, 46.210; IQR, 21.8s) took to complete the marker placement task was 31% slower ($p < 0.001$) than the one taken by those participants using the telestrator condition (median, 31.85; IQR, 12.8s). Participants using the STAR platform (μ, 256.8; σx, 56.2s) performed the abdominal incision task 24% slower ($P = 0.013$) than those using the telestrator condition (μ, 194.1; σx, 31.6s).

  Participants that used the STAR platform performed the tasks slightly more slowly than those using the telestrator condition. We believe this was due to the difference in the way each condition presented the visual feedback to the trainee. Because the 3D annotations provided by an ARHMD can more precisely show the correct location on the patient's body, participants may take longer to follow the instructions because they are trying to be more precise.
- **Focus shifts:** The average number of focus shifts across participants was reduced by 92% in the anatomical marking task [11.1 vs 0.8] ($p < 0.001$) and by 78% during the abdominal incision task [34.5 vs 4.2] ($p < 0.001$). Participants using the telestrator showed hesitation turning their heads twice or more, to double check the location indicated by the mentor.
- **Workspace Efficiency:** Table 1 summarizes the results of the workspace efficiency analysis. The ARHMD avoided 4.8 collisions for Task 1 on average, and 3.8 collisions for Task 2. The duration of the potential collisions on average is 3.2s and 1.3s, respectively. For some participants, Task 1 implied as many as 27 collisions, totaling 51% of the task completion time. The results from our workspace efficiency metrics show that participants often moved their arms in ways that would have collided with a tablet if the tablet had been present. While this does not mean that users would collide with the tablet if they were actually using a tablet-based system, it does mean that participants would have to alter their natural behavior to perform the tasks.
- **Questionnaire:** Participants agreed that the conditions provided them with enough capabilities to complete the procedure; however, the STAR system was considered more favorable (8.571 vs. 7.5). The same is true for how easy it was to follow the instructions (8.571 vs. 6.875); ease of use of the telementoring condition (7.143 vs. 6.875); efficiency

in the information exchange (7.143 vs. 4.375); and reduction in time taken to complete the procedure with respect to the telestrator condition (6.429 vs. 5.0). Likewise, participants commented that the STAR platform generated less frustration (-7.857 vs. -4.375) and a less negative impact in the amount of time taken to complete the procedure (-5.714 vs. -4.375) when compared to the telestrator condition. In the comments and suggestions section of the questionnaire, participants found the STAR platform useful and interesting, but commented that the field of view of the display was limited and that the imagery may produce headaches when the HMD was not adjusted correctly to the head of the participant.

Table 1. Summary of workspace efficiency analysis. Collision durations of over 50% of the total time taken demonstrate the encumbrance of tablet-based systems.

Metric	Task 1				Task 2
	Trial 1		Trial 2	Trial 3	
Number of collisions	AVG	5.7	4.6	4.1	3.8
	MAX	24	27	14	24
Collision duration	AVG	4.4s 8.7%	2.5s 7.6%	2.7s 7.8%	1.3s 0.68%
	MAX	28.8s 43%	13s 51%	17s 39%	15.7s 8.8%

In general, we found that the transition from a 2D to a 3D visualization of annotation was a great improvement, because it preserved the depth perception that is so crucial when performing dexterous tasks. In addition, the ARHMD provides advantages in the form of mobility and ease of deployment. The HMD allows users to view graphical content from arbitrary viewpoints, as opposed to the tablet system that requires manual and cumbersome repositioning. One notable result is that we have demonstrated that a tablet-based surgical telementoring system would introduce encumbrance issues in terms of arm position that an ARHMD-based approach would not have. The introduction of 3D graphical annotations that give trainees proper depth perception is a powerful new feature that ARHMDs can offer, which encourages future research into telementoring systems that use this emerging technology.

Upgrade of the large-scale table-based interaction interface

As part of the development done to improve the interface used by the mentor, a new model of touch screen was purchased. This purchase was mentioned in the previous report. After the purchase, development begun on migrating the existing mentor codebase to a new codebase compatible with the new screen. This resulted in a C# implementation of the Mentor System that uses Windows Touch API to handle the touch events produced by the mentor. The new system was coded as a Universal Windows Platform application, which allows the application to be deployed easily into other platforms. The graphical user interface of the Mentor System was also modified: the annotation panel was modified with a sliding panel, and the buttons were relocated for ease of reach. Figure 8 presents a screenshot of an instruction created with the Mentor System. The background image is the live video sent by the trainee, and the mentor, via touch inputs, created the annotations appearing in the screen.

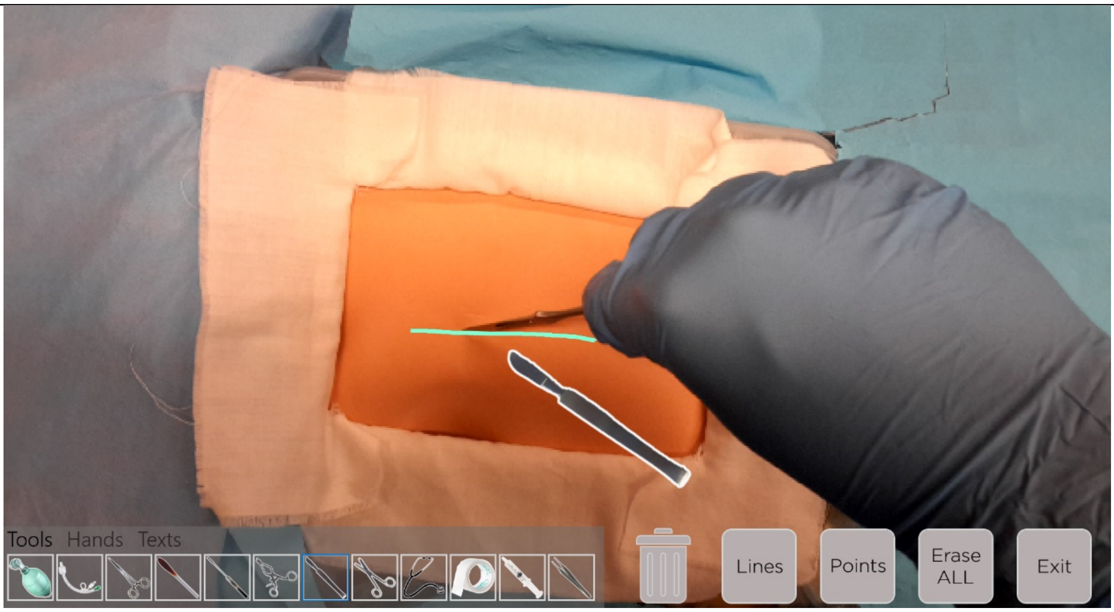


Figure 8. User interface on the updated version of the table-based Mentor System

Experimental Design 5 - Validate STAR in fasciotomy context

The experiment took place in Indianapolis, with the mentor system running from a conference room in the Trauma Department at Eskenazi Hospital, while the trainee system was set up in the IUSM Skills Laboratory at Van Nuys Building. To demonstrate the remote communication capabilities of the STAR platform, the mentor needed to be located in a building outside of the IUSM campus, which introduces a considerable geographic distance between the Mentor and the Trainee Systems. For this purpose, the room selected for the Mentor System to be is located in the Sidney & Lois Eskanazi Hospital, located about 500m away from the Van Nuys building, where the trainees will be. For the purpose of this experiment, this distance is considered to be sufficient to target the presented motivation, as more distance will introduce extra logistics that would need to be considered (e.g. mentor and team members transportation to the location). Figure 9 presents the location of both the buildings to be used during the experiment.

In order to introduce the less possible encumbrance, an approach to put the previously discussed top-down camera without the use of a tripod or any other artifact was explored. The solution for this problem will be to attach a pan/tilt camera to the operating lights structure. For this purpose, a 3D piece was modeled and printed: this piece fits the mechanical arms of the operating lights structure, and allows the camera to be fixed to it. The piece will be attached to the arm that holds the information monitor, which will allow the trainees to move the operating lights without moving the camera in the process. Figure 10 presents the design of the 3D modeled piece, as well as how the camera will be placed in the operating lights structure using the piece.

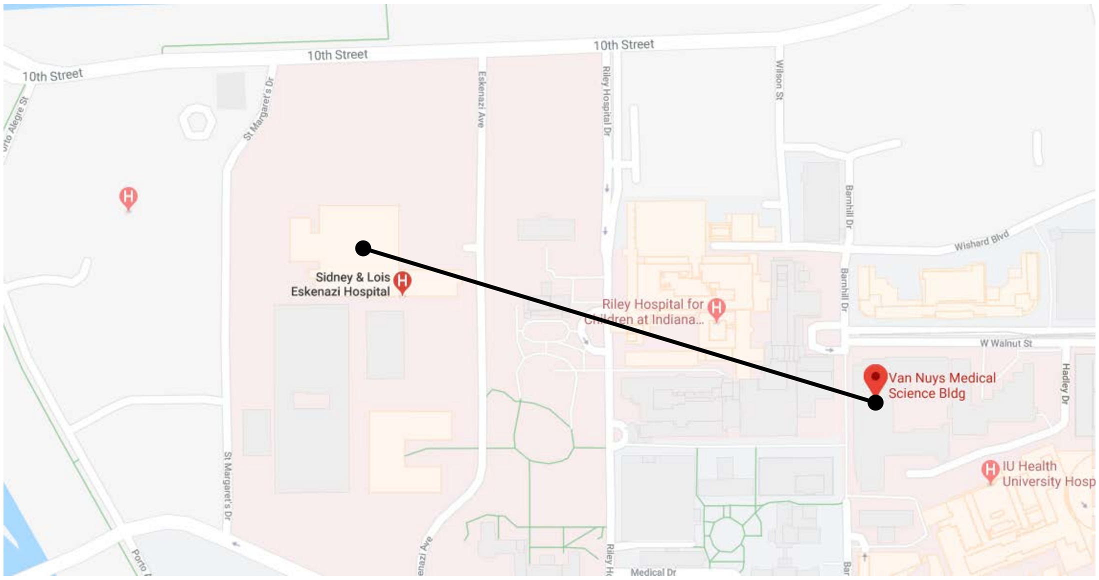


Figure 9. Van Nuys Building and Eskenazi Hospital. The buildings are located about 500m away from each other.

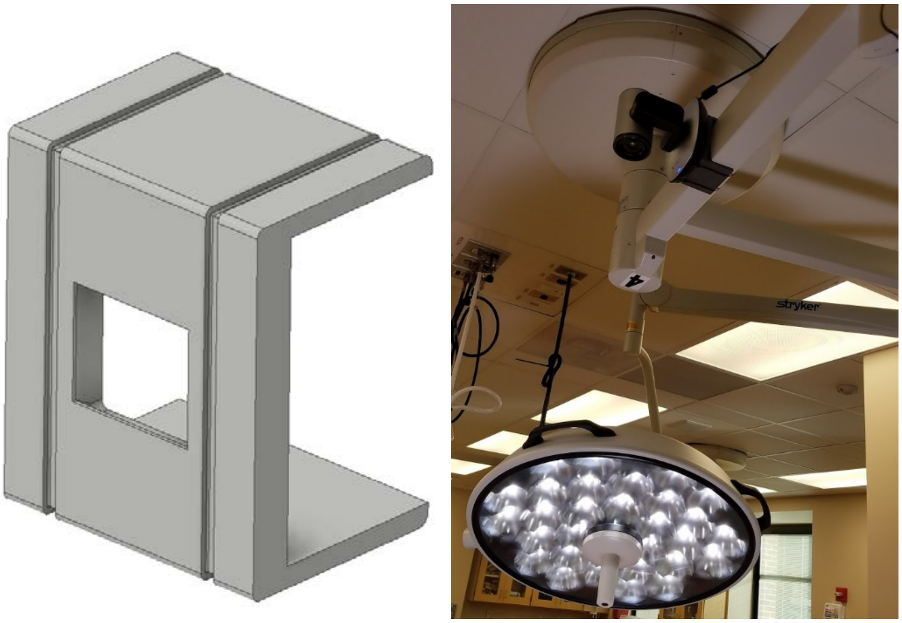


Figure 10. CAD model design and usage of piece to position the top-down camera on the surgical lights mechanical arm.

The experiment was conducted with cadaveric specimens: twenty cadaver legs were purchased to perform a compartment release fasciotomy procedure. The setup at the mentee side included two operating stations (divided by a mobile curtain) to carry out fasciotomies under two mentoring conditions: Alone vs STAR. Each station was equipped with one operating table, a set of surgical lights, a tripod-mounted camera (for recording purposes), and a Mayo stand with various surgical instruments. One nurse assistant (per condition) stood by the mentees, assisting them throughout the procedure in aspects such as fluids cleaning, and instrument handing. In addition, the STAR workstation included a top-down pan/zoom/tilt camera attached to the surgical lights' video monitor, the AR HMD-based Trainee System that the mentees wore to visualize the specialist-authored surgical instructions, and a phone to have audio communication with the remote specialist. The setup at the mentor side included a table in which the Mentor System was located, and a conferencing speakerphone used to establish the audio communication with the mentee. Figure 11 includes a schematic from both the mentor (*top*) and mentee (*bottom*) sites.

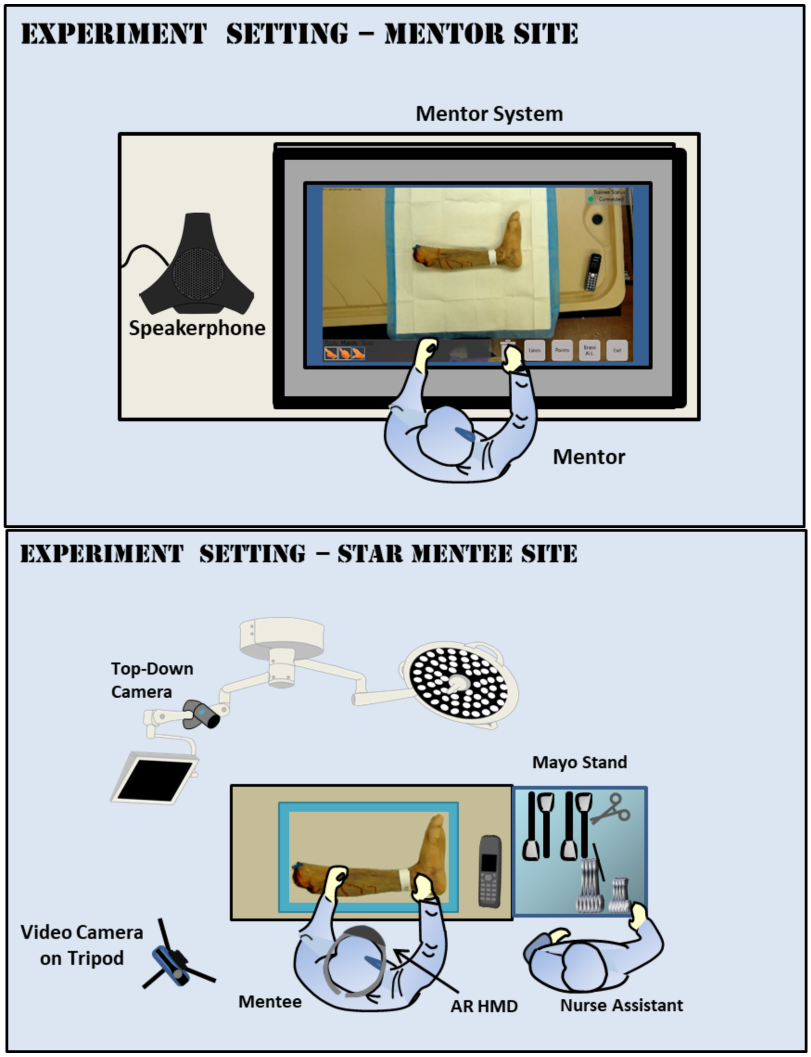


Figure 11. Experimental setting. *Top*: Mentor station. The mentor uses the Mentor System to create annotations over the live video feed. *Bottom*: STAR Trainee station. The mentee wear the AR HMD and visualizes the surgical guidance sent by the remote specialist.

The main hypothesis to be tested during this experiment is that trainees using the STAR platform can perform a fasciotomy of the lower leg faster and with fewer mistakes than trainees who are not mentored. Twenty participants, medical students and residents from surgical programs among them, volunteered to participate and were randomly assigned to one of the two experimental conditions considered:

- **Alone (A):** The participant was encouraged to review the procedure using the Advanced Surgical Skills for Exposure in Trauma (ASSET) guide book before conducting the procedure alone, assisted by a nurse in charge of delivering tools. Figure 12 (*left*) portraits this condition.

- **STAR (S):** The participant would wear the ARHMD running the STAR Trainee subsystem, and would receive remote guidance while performing the procedure next to a nurse assistant delivering tools. Figure 12 (*right*) portraits this condition.

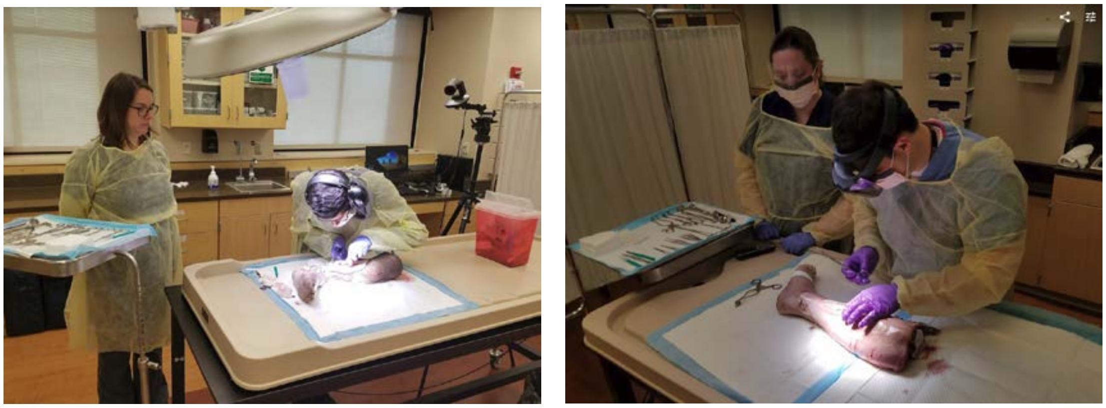


Figure 12. Two experimental conditions randomly assigned to the participants: performing the fasciotomy alone previously reviewing the ASSET book (left), receiving remote guidance using the STAR ARHMD trainee subsystem.

A total of 14 medical residents and 6 medical students (12 male, 6 female, 2 did not answer) were divided into the two experimental conditions: 7 residents and 3 medical students per condition, giving a between subject design with N = 10. The age range was between 22 and 35 years old, with a mean of 28.5 ± 3.3. Medical students varied between first (2), second (1) and fourth (3) year, while residents were in their first year (4), third (3), fourth (4) in different areas such as general surgery, research, and labs. Two expert surgeons, who are also faculty at IUSM, guided the participants using the STAR system throughout the experiment.

To assess performance during the procedure, the metrics used were completion time and Individual Performance Score (IPS). All participants were recorded as well as evaluated on site during the execution of the procedure. Additional metrics were considered as the number of errors during the procedure, and self-reported confidence value, acquired before and after the procedure. Participants were also asked to fill out a post-experiment questionnaire to assess their experience through the procedure with the assigned mentoring method (Alone vs STAR).

The IPS metric was originally developed by Mackenzie et al (2015)[1] to evaluate the performance of surgical residents before and immediately after ASSET training, with follow-up evaluation 12 to 18 months later to determine skill retention and competence. IPS includes five components of technical and non-technical skills: knowledge, anatomy, management, procedural steps, and technical points. Secondary metrics for IPS include Global Rating Scales (GRS) and Evaluator's Overall Rating (EOR). The original work included IPS metrics for three exposure procedures: axillary artery, brachial artery and femoral artery. Evaluators were introduced to a script to assess performance for each section of the procedure and the metric. Modifications were made to adapt the IPS metrics to the fasciotomy of the lower leg procedure.

---

[1] Mackenzie, C. F., Garofalo, E., Shackelford, S., Shalin, V., Pugh, K., Chen, H., Puche, A., Pasley, J., Sarani, B., Henry, S., & Bowyer, M. (2015). Using an individual procedure score before and after the advanced surgical skills exposure for trauma course training to benchmark a hemorrhage-control performance metric. *Journal of surgical education*, *72*(6), 1278-1289.

Six sections were developed towards the main IPS score in the evaluator's script for fasciotomies: Anatomical Landmarks, to be highlighted before any incision is performed showing where the initial cut should be made on the leg anteriorly and posteriorly; Anterolateral incision, where the participants needed to identify and release the fascia from the anterior and lateral compartments; Posteromedial incision, where participants were required to identify and released the superficial posterior and the deep posterior compartments; General performance evaluation included three sections, namely Technique points, Expert Discriminator Operative Field Maneuvers for fasciotomy procedure, and Expert Discriminatory Instrument Use for fasciotomies. Each section of the main IPS score was normalized to 100 maximum score. The IPS metric thus had a maximum of 600 overall.

A second version of the metric was a weighted average of all the sections' scores to assign a level of importance of the section towards the execution of the fasciotomy procedure. Initial weight distribution was as follows: Anatomical Landmarks (0.15), Anterolateral Incision (0.35), Posterolateral Incision (0.35), Technique (0.05), Maneuvers (0.05) and Instrument Use (0.05). The maximum for this weighted IPS (WIPS) was 100. The values of the weights are preliminary and could be changed to reflect the opinions of expert surgeons through a separate evaluation of the IPS metric and thus the importance of each section to accurately assess the performance of the procedure.

Secondary metrics were included in the evaluator's IPS script to assess the Global Rating Scale (GRS) and Evaluator's Overall Rating (EOR). GRS contains 4 questions with a 5-point Likert scale assessing the overall understanding of the anatomy, the technical skills and the ability of the participant to perform the procedure alone. GRS score was the average of all 4 responses normalized to 100. EOR is a numeric value (maximum score 100) subjectively assigned by the evaluator, selected from 5 ranges provided in the script (<60, 60-69, 70-79, 80-89, ≥90) that describe how well the participant performed.

The number of errors in the procedure were the aggregate of the errors highlighted in the evaluator's script during the procedure's evaluation. There were a total of 11 identifiable errors associated to procedural steps and identifying and protecting anatomical structures at risk.

In addition to the IPS-related metrics, a self-reported confidence assessment allowed us to quantify the change in confidence level each participant feels towards performing a fasciotomy of the lower leg. The confidence assessment contained 4 questions with 5-point Likert scales inquiring their confidence about anatomical landmarks, procedural steps, technique and handling instruments, as well as how confident they feel to perform the procedure on their own. Given the varied experience range from the participants, we used as metric the difference between post-experiment and pre-experiment self-reported confidence, to give us some insight as to how the mentoring experience (or lack thereof) might have influenced their confidence level.

Finally, Once the participants had completed the procedure with the assigned mentoring condition, they were asked to fill out a questionnaire, which included 8 questions with a 5-point Likert scale and an additional open-ended question for comments. These questions referred to different aspects of performing the procedure with the assigned mentoring condition:

- Q1: Sufficient information to perform the procedure
- Q2: Instructions were easy to follow
- Q3: Effective instruction conveyance
- Q4: Helped clear doubts
- Q5: Helped reduce completion time

- Q6: Mentoring method generated frustration
- Q7: Mentoring method better than side-by-side
- Q8: Mentoring method worse than side-by-side

Expert surgeons from the research team assessed the participants' performance. Table 2 summarizes the quantitative metrics averaged over all participants in each condition, namely: completion time (in seconds), IPS, WIPS, errors, GRS and EOR. Values are reported as median ± interquartile range unless specified otherwise.

Table 2. Summary of results for all quantitative metrics averaged over participants in each condition. Metrics with * are reported as mean ± standard deviation.

Metrics	ALONE	STAR
Completion Time	1400.0 ± 685.0	1379.0 ± 380.5
IPS*	437.4 ± 96.8	483.1 ± 65.3
WIPS*	71.7 ± 18.6	82.5 ± 6.4
Errors*	1.8 ± 1.4	0.6 ± 0.7
GRS	60.00 ± 46.67	56.65 ± 29.95
EOR	76.5 ± 27.5	75.0 ± 12.0

A statistical analysis was conducted to compare the experimental conditions as independent variables, using the aforementioned metrics as dependent variables. The null hypothesis for all comparisons was that both mentoring conditions (Alone and STAR) are the same. For the alternative hypothesis, all metrics were considered for a one-sided comparison: for errors and completion time, STAR was less than Alone, whereas all other metrics STAR was higher than Alone. The normality assumption of the data was evaluated using the Shapiro-Wilk test. When data pointed to non-normality, the nonparametric Mann-Whitney test was used to compare populations with unpaired data, whereas the nonparametric Wilcoxon signed-rank test was used to compare populations with paired data. For normal data, a Levene's test was run to assess data's equal variance condition; as data pointed to equal variance, a regular 2-sample t-test was used over the data.

Considering all participants in each condition, only two comparisons showed statistical significance: the number of errors were significantly lower for STAR than Alone ($p = 0.03$) and WIPS scores were significantly higher for STAR than Alone ($p = 0.04$). Even though completion time did not show a significant difference, the mean value for STAR was slightly lower than performing the procedure without mentoring. This metric can be misleading since the inherent interactions created by mentoring can be more time consuming due to larger information exchange.

The subjective metrics GRS and EOR showed large variances so the null hypothesis could not be rejected in either case. Given the resolution level of the metrics, they were not considered for further analysis.

Additional analyses were performed when considering the expertise of the participants. Given the equal number of residents and medical students in each mentoring condition three sub-groups were considered: only medical students, only residents, and a sub-group that merged medical students and first year residents. The latter is considered the group who would benefit the most from an interactive mentored experience due to their lower experience level. Table 3 shows the means and standard deviations of three of the metrics mentioned earlier: IPS, WIPS and errors. When considering only the residents of each condition, the null hypothesis could not be reject in any of the metrics. This suggests that surgical residents, particularly the ones advanced in their residency, do not benefit much from mentoring a procedure like a lower leg fasciotomy.

For the sub-group of medical students only, errors were significantly lower when mentored with STAR than when performing the fasciotomies alone (p = 0.01), and WIPS scores were significantly higher for STAR than alone (p = 0.04). We understand that small sample size makes these results not as relevant however the trend remains. When the third group is considered, the one formed by medical students and first year residents, there is an increase in sample size from 3 to 5 per condition.

Table 3. Participants' performance considering their expertise per condition

Metric	ALONE			STAR		
	Med Students (n=3)	Residents (n=7)	Med Students and 1st Year Residents (n=5)	Med Students (n=3)	Residents (n=7)	Med Students and 1st Year Residents (n= 5)
IPS	366.5 ± 58.8	467.8 ± 96.5	376.4 ± 46.2	462.8 ± 88.6	491.8 ± 59.0	451.6 ± 69.7
WIPS	57.2 ± 19.4	77.9 ± 15.6	58.9 ± 14.5	84.1 ± 6.7	81.8 ± 6.6	82.8 ± 6.1
Errors	2.7 ± 1.2	1.4 ± 1.4	2.6 ± 0.9	0.3 ± 0.6	0.7 ± 0.8	0.2 ± 0.4

Additionally, the difference between mentoring condition was statistically significant in all considered metrics: number of errors were significantly lower for STAR than Alone ($p < 0.001$), and both IPS and WIPS were significantly higher for STAR than Alone ($p = 0.03$ and $p < 0.01$ respectively). These results generally support the main hypothesis that using STAR telementoring will lead to better performance with lower errors.

The analysis for this metric focused on the average increment in confidence per condition. The comparisons were made with a sample size of ten participants per condition (*N = 10*). The independent variable was the mentoring condition used, and the dependent variable was the increment of confidence level for each of the questions on the self-confidence assessment. Each of them covered the participant's confidence level regarding:

- Identifying anatomical landmarks
- Knowledge of procedural steps
- Instrument handling technique
- Ability to perform the procedure alone

Average increment in confidence across all participants and all questions for STAR participants was 1.28 on a 5-point scale, whereas participants without mentoring only showed an increase of 0.675. The difference between the average confidence increment was statistically significant (p = 0.017) when comparing the two mentoring conditions. Tables 4 and 5 report the difference between the participants' confidence level before and after experiment, for the Alone and STAR and conditions respectively. STAR participants reported a significant improvement in all categories, whereas Alone participants had significant improvements in only half of the categories. In addition, Tables 6 and 7 report the initial and final confidence levels from the participants.

STAR significantly improved the participant's confidence in all the evaluated aspects. In addition, a breakdown of the obtained differences reveals that participants in the Alone condition reported to be more confident than those in the STAR condition before the experiment, but participants in the STAR condition reported to be more confident than those in the Alone condition after the experiment. This change in the participants' confidence levels reveals that the platform positively influenced the mentee, effectively transferring the surgical expertise from a remote specialist.

Table 4. Participants' self-reported confidence scores for the Book condition. Only p-values with an asterisk (*) represent a significant improvement in the participant's confidence level.

Confidence Assessment Aspect	Self-Reported Confidence Difference	p-value
Identify anatomical landmarks	1 ± 1.00	0.022*
Knowledge of procedural steps	1 ± 2.00	0.036*
Instrument handling technique	0 ± 1.00	0.225
Perform procedure alone	1 ± 0.25	0.11

Table 5. Participants' self-reported confidence scores for the STAR condition. All p-values report a significant improvement in the participant's confidence level.

Confidence Assessment Aspect	Self-Reported Confidence Difference	p-value
Identify anatomical landmarks	1.0 ± 1.25	0.014*
Knowledge of procedural steps	1.0 ± 1.00	0.006*
Instrument handling technique	1.0 ± 1.25	0.014*
Perform procedure alone	1.5 ± 1.00	0.006*

Table 6. Participants' self-reported confidence after the experiment.

Confidence Assessment Aspect	STAR Post Confidence	Alone Post Confidence
Identify anatomical landmarks	4.00 ± 1.25	4.00 ± 1.00
Knowledge of procedural steps	4.00 ± 0.00	3.50 ± 1.25
Instrument handling technique	4.00 ± 2.00	4.00 ± 2.00
Perform procedure alone	3.50 ± 1.00	3.50 ± 1.50

Table 7. Participants' self-reported confidence before the experiment.

Confidence Assessment Aspect	STAR Pre Confidence	Alone Pre Confidence
Identify anatomical landmarks	3.00 ± 1.25	3.50 ± 1.00
Knowledge of procedural steps	3.00 ± 0.50	2.50 ± 2.00
Instrument handling technique	3.00 ± 2.00	4.00 ± 1.50
Perform procedure alone	2.00 ± 1.25	3.00 ± 1.25

Table 8 shows the average questionnaire results across participants. Responses regarding the amount of information being sufficient to complete the procedure and the ease to follow instructions favors STAR than Alone with statistical significance. Participants also disagreed with the statement that STAR mentoring generated frustration significantly less than performing the procedure alone. Lastly, when comparing the two mentoring conditions covered by this experiment, participants disagreed with the statement that STAR was worse than side-by-side mentoring significantly more than when performing Alone. No significance was found for the comparison "the mentoring method was better than side-by-side" although STAR received higher scores than no mentoring at all.

Table 8. Participants' usability questionnaire answers. P-values with an asterisk (*) represents a significant difference between the conditions. For questions 6 and 8, a lower score is preferred.

Question	STAR Responses	Alone Responses	p-value
[1] Sufficient amount of information to complete procedure	5.0 ± 1.00	4.0 ± 0.50	0.024*
[2] Easy to follow instructions	5.0 ± 1.00	4.0 ± 1.25	0.018*
[3] Method conveyed instructions effectively	4.0 ± 1.25	4.0 ± 1.00	0.415
[4] Method helped to clear doubts during procedure	4.0 ± 1.25	3.0 ± 1.50	0.063
[5] Method helped reduce time taken to complete procedure	5.0 ± 2.25	3.5 ± 2.25	0.111
[6] Method generated frustration	2.0 ± 1.25	3.0 ± 2.00	0.037*
[7] Mentoring better than side-by-side	2.0 ± 2.00	2.0 ± 1.00	0.139
[8] Mentoring worse than side-by-side	2.5 ± 2.25	4.0 ± 2.00	0.028*

Task 4.1- Refine STAR platform for a fasciotomy on a cadaveric leg

Rural assistance via top-down drone camera

As mentioned before, there are advantages of having a top down camera instead of just a first-person view from the HoloLens. In an austere environment, having a stationary camera at the site is obviously out of the question. For this reason, the team decided that having a drone stream live video feed from the site would be a viable option to provide a top-down view in rural locations. Figure 13 provides a proof-of-concept of the rural emergency assistance with STAR. Video streaming from the drone has been implemented on the Matrice100, a developer drone from DJI, attached to a DJI Manifold. The Manifold is an embedded computer designed to work with the DJI OnBoard SDK. It has low power consumption, allowing it to be powered by the drone's battery when flying. Its Quad-core, 4-Plus-1™ ARM® processor and Low-power NVIDIA Kepler™-based GeForce® graphics processor allows high performance computing. The camera being used for obtaining live feed with the drone is the Zenmuse X3, capable of obtaining 4K quality video. It includes a 3-axis gimbal, which provides better stabilization when capturing the video.

Figure 13: STAR proof-of-concept for an emergency rural assistance telementoring platform. A drone hovers over the patient to provide the remote mentor with a stable view of the operating field

Due to improvements to the whole system, the streaming protocol was changed to Web Real-Time Communication (WebRTC). This approach has several advantages over traditional server-client video streaming protocols, including lower latency, improved reliability, and more security in the communication.

Implementation of the streaming was implemented in the DJI Manifold embedded computer, connected to the DJI Matrice100 Drone, with video feed from the Zenmuse X3 camera. The video is accessed from the Manifold using the DJI OnBoard SDK, which includes Robot Operating System (ROS), packages to access and control several aspects of the Matrice 100 drone. For this purpose, we specifically use the **dji_sdk_manifold_read_cam** ROS package. When running the package, the video is published on the ROS topic dji_sdk/image_raw. When a WebRTC application is run, the application looks for external video and audio devices (e.g. webcams). It then streams the information from these devices to a signaling server. The signaling then proceeds to redirect the media to its destination, making sure the communication capabilities and resources are good enough for proper quality of the information to reach and be accessed or displayed at the destination. The Manifold does not recognize the Zenmuse camera as an external video device. To be able to stream via WebRTC, the pipeline was to first create a virtual video device, and then stream the video from the ROS topic to this virtual device. Consequently, when connecting to a WebRTC application, it will recognize this virtual video device, read it as if it were and "ordinary" video device, and send the media in it via WebRTC to its destination. The destination and communication resources are handled by the WebRTC app, which in this case is the same application that streams video from the HoloLens to the mentor table. To create the virtual video device, the kernel module v4l2-Loopback was used.

Once the virtual video device is created, we can run the **dji_sdk_manifold_read_cam** package to publish in real time the video to the corresponding ROS topic. To send the video from a ROS topic to a virtual capture device, the ROS node ros-virtual-cam is run. The target device, target size, target pixel format, and source topic all have to be specified when running the ros-virtual-cam node. Once all this information is specified and run, the media on the ROS topic will be presented in real time as if it were captured by the virtual video device, thus succesfully "fooling" the WebRTC application to send that media.

Moreover, tests of this streaming were done when having the manifold connected via Wi-Fi. In real austere environments, expecting Wi-Fi to be available is not realistic. However, the Manifold now has a mobile internet connection. This is the case because a Wi-Fi 4G LTE Global USM Modem U620L is used. When connecting via USB and with a data plan, the USB connection gives fast LTE speeds to the Manifold. As a result, in an austere environment, if there is cell coverage, the video from the drone's camera could be streamed in real time to the Mentor System. Figure 14 displays the image obtained by the drone-mounted camera in the Mentor System application.

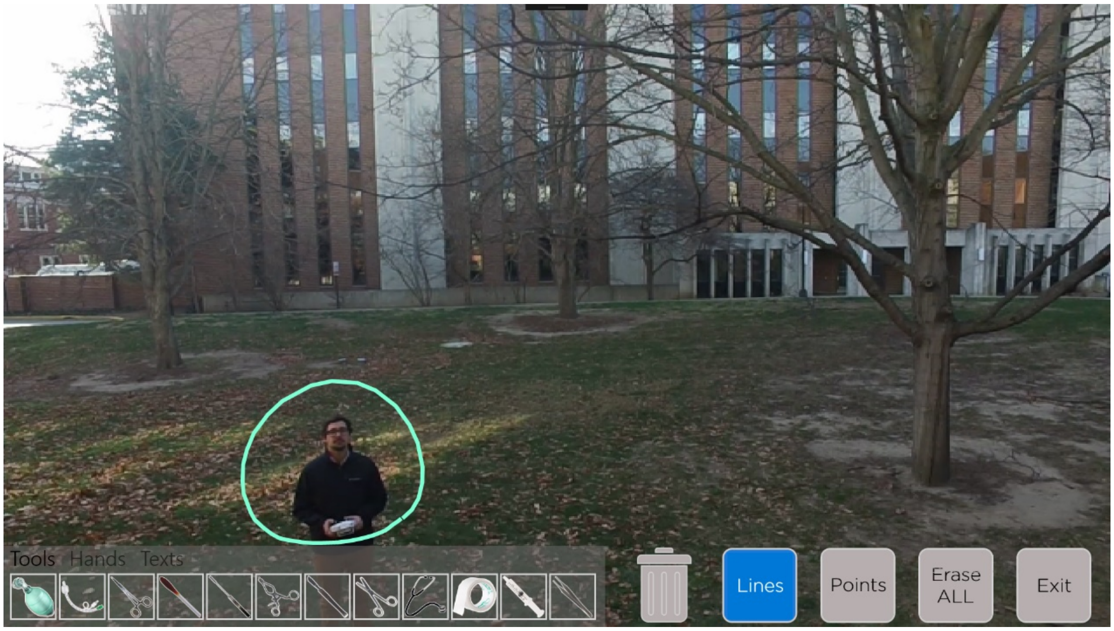


Figure 14: Real-time video streaming from drone to the Mentor System.

Task 1.2- Achieve visual overlay of information

Subtask 1.2.2: Generate illustration of next steps of surgery through simulation.

Evaluation of Visualization of Future Steps in Tablet Telementoring System

As it was reported before, a tablet-based system to visualize the futures steps in a surgical procedure was developed. This system was integrated with the current tablet-based version of the Trainee System, and provides the trainee with a backup plan to follow a surgical procedure in situation in which the communication with the mentor is not robust or in cases in which there is no mentor at the other end of the communication. Figure 15 presents the architecture of the system.

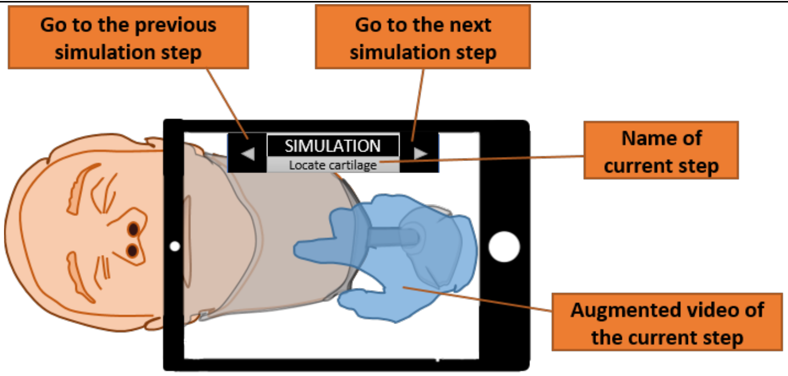
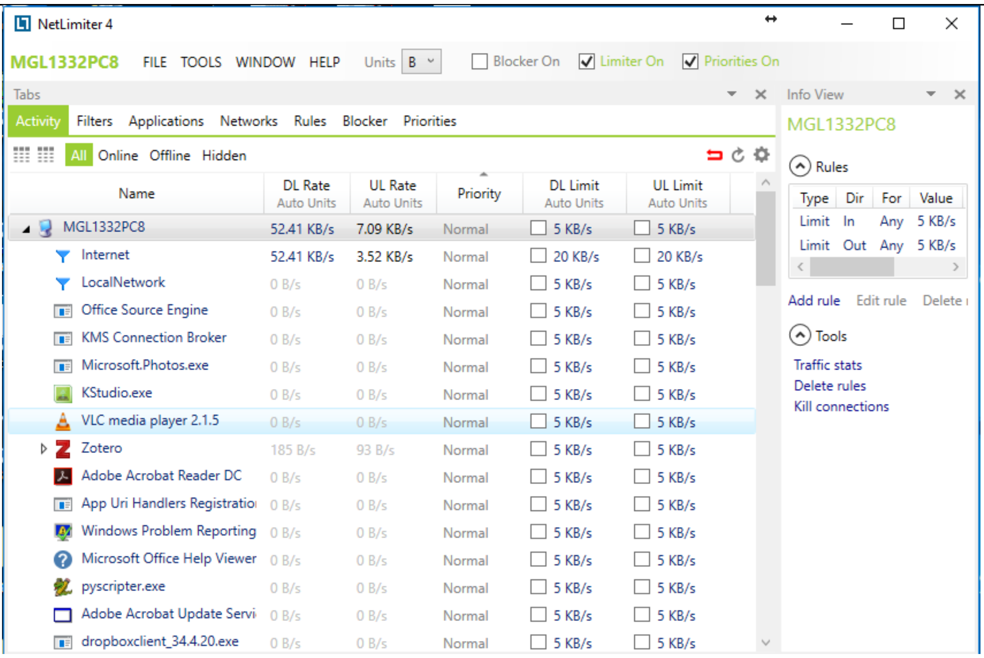


Figure 15. Trainee's tablet interface to display future steps of cric procedure

An experiment was designed to assess the capabilities that this system provides. The experiment was conducted at Purdue University, and participants had to complete a surgical procedure (cric) under two conditions: telestrator-based telementoring and telementoring using STAR. The goal of this experiment was to compare these two conditions in terms of how well they can cope with austere conditions, namely problems with the communication between mentor and trainees.

The logistics of the experiment are described. Twenty participants with no prior surgical experience were asked to conduct a mock cricothyroidotomy procedure on a patient simulator. To do this, the participants were guided by a remote mentor, one of the team member of the project who was trained beforehand to conduct this procedure by surgeons at Indiana University School of Medicine. Participants had to replicate the instructions conveyed by the live mentor, which were received in the form of audio (provided by a Skype call) and various types of visual annotations. For this experiment, the mentor was in a different building than the trainees. Recordings per participant were obtained.

However, as it was mentioned before, this experiment was designed to simulate austere conditions. The intuition behind this experimental design is that surgical telementoring systems should provide their users with enough capabilities to keep providing medical assistance, regardless of the quality of communication with the mentor or even in cases in which the mentor is not available. By using a script that controlled a bandwidth limiter software (Netlimiter 4, Figure 16), the experimenters could artificially simulate drops in the internet speed, which directly impacted the quality of the communication between mentor and trainee during the experiment. Activating and deactivating the NetLimiter software in pseudo-random intervals resulted in drops of the audio quality, making it almost impossible for the trainee to understand what the mentor was speaking during these drops of communication.



Name	DL Rate Auto Units	UL Rate Auto Units	Priority	DL Limit Auto Units	UL Limit Auto Units
MGL1332PC8	52.41 KB/s	7.09 KB/s	Normal	☐ 5 KB/s	☐ 5 KB/s
Internet	52.41 KB/s	3.52 KB/s	Normal	☐ 20 KB/s	☐ 20 KB/s
LocalNetwork	0 B/s	0 B/s	Normal	☐ 5 KB/s	☐ 5 KB/s
Office Source Engine	0 B/s	0 B/s	Normal	☐ 5 KB/s	☐ 5 KB/s
KMS Connection Broker	0 B/s	0 B/s	Normal	☐ 5 KB/s	☐ 5 KB/s
Microsoft.Photos.exe	0 B/s	0 B/s	Normal	☐ 5 KB/s	☐ 5 KB/s
KStudio.exe	0 B/s	0 B/s	Normal	☐ 5 KB/s	☐ 5 KB/s
VLC media player 2.1.5	0 B/s	0 B/s	Normal	☐ 5 KB/s	☐ 5 KB/s
Zotero	185 B/s	93 B/s	Normal	☐ 5 KB/s	☐ 5 KB/s
Adobe Acrobat Reader DC	0 B/s	0 B/s	Normal	☐ 5 KB/s	☐ 5 KB/s
App Uri Handlers Registratio	0 B/s	0 B/s	Normal	☐ 5 KB/s	☐ 5 KB/s
Windows Problem Reporting	0 B/s	0 B/s	Normal	☐ 5 KB/s	☐ 5 KB/s
Microsoft Office Help Viewer	0 B/s	0 B/s	Normal	☐ 5 KB/s	☐ 5 KB/s
pyscripter.exe	0 B/s	0 B/s	Normal	☐ 5 KB/s	☐ 5 KB/s
Adobe Acrobat Update Servi	0 B/s	0 B/s	Normal	☐ 5 KB/s	☐ 5 KB/s
dropboxclient_34.4.20.exe	0 B/s	0 B/s	Normal	☐ 5 KB/s	☐ 5 KB/s

Type	Dir	For	Value
Limit	In	Any	5 KB/s
Limit	Out	Any	5 KB/s

Figure 16. Screenshot of the NetLimiter software's window

As explained before, trainees could communicate with the mentor both using audio in addition to the telementoring condition they were assigned to. These conditions are explained:

- **Telestrator-based telementoring**: In this condition, a screen was positioned in front of the trainee; the trainee was supposed to retrieve the guidance from this screen. The screen was connected to the computer that hosted the Skype call. Using the shared screen feature of Skype, the image of the mentor's computer was shown to the trainees. The guidance from the mentor consisted in a set of images that the mentor was displaying in its computer and that the trainee was able to see because of the screen sharing. This set of images illustrated each of the steps of the cric procedure, enhanced with some pre-generated line annotations to communication orientation of cuts, direction of motion, among others. Figure 17 portraits the setup for this condition.
- **STAR-based telementoring**: For this condition, participants were using the tablet-based STAR platform with the ability to visualize the future steps of a cric procedure. Participants were looking at the patient simulator through the display of the tablet, which showed the annotations sent by the mentor consisting in lines and icons of surgical instruments. The mentor was able to send these annotations by using the STAR Mentor System, which was communicating remotely with the Trainee System over the internet. In addition to the STAR platform, the mentor was able to communicate via audio with the trainees using the same Skype setup used for the previous condition (without the screen sharing). Figure 18 portraits the setup for this condition.

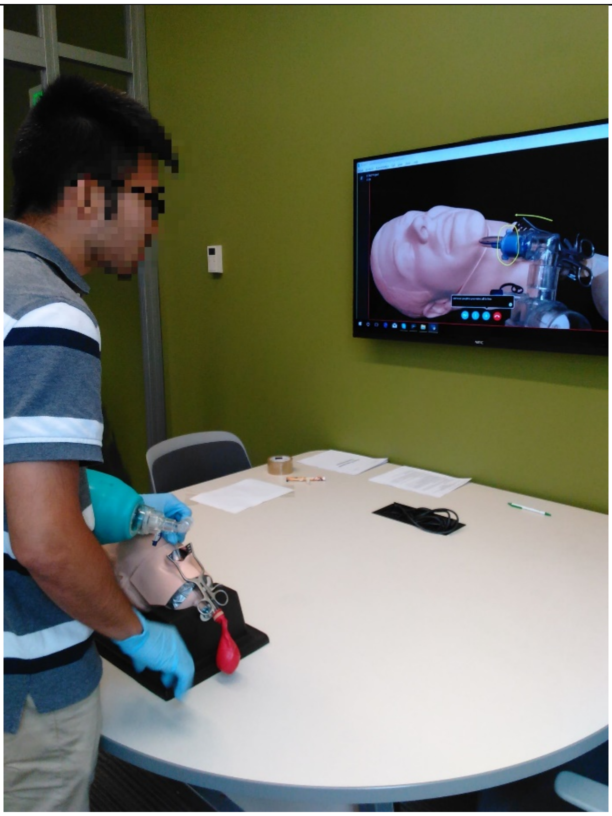


Figure 17. Experiment setup for the telestrator telementoring condition.

Figure 18. Experiment setup for the STAR telementoring condition.

Figure 19 provides a diagram that explains the architecture of the experiment.

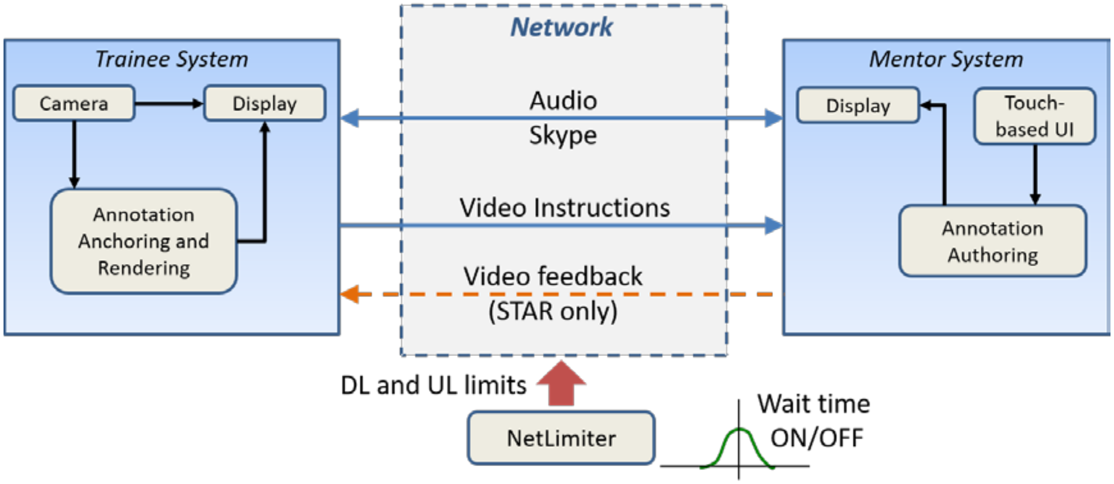


Figure 19. Experiment architecture diagram.

The premise of the experiment consisted in observing the behavior of trainees following surgical instructions in an austere environment scenario. Since the STAR platform provided the visualization of future steps feature, the experimenters expected participants using this condition to finish the procedure in a better way, even when experiencing faulty communications. To assess the participants' performance, three different metrics were used:

- **Idle time ratio**: This metric is defined as the ratio between how much time participants remained idle (not doing any action) and the total time taken to complete the procedure. This provides an estimation about how much time was wasted because of the faulty communications participants experienced.
- **Recall Error**: This metric is measurement of how close participants were able to describe what they remembered of each of the steps of the surgical procedure. To obtain this metric, a text string with the words that represent each step of the procedure was created (considered as ground truth). A text string like this was extracted for each participant too (each participant had to write what they remembered of each procedure step). After that, by treating these strings as vectors of words, the vector distance between what participants wrote and the ground truth was calculated. Therefore, a lower distance score meant that participants were able to remember and explain the steps they just did in a better way.
- **Performance score**: This metric represents how well did the participant performed each step of the procedure. After watching each participant's recording, another team member (also considered as an expert in the cric procedure) accessed the participants performance, following the steps shown in the United States Marine Corps Emergency Cricothyroidotomy Steps (FMST 1418). The expert assigned a score (0 to 3, 0 being the lowest) depending on how well the instruction was performed.

A summary of the results obtained from this study is presented in Figure 20. The results indicate the STAR system excelled in all the metrics when compared to the traditional telestrator-based telementoring. On average, each participant in the STAR condition used the visualization of feature steps feature 5 times. The idle time rate of participants using STAR was less 48% than those using telestrator (0.279 vs 0.145; $p < 0.001$). In addition, participants using STAR showed 26% more accurate step recollections when compared to those using telestrator (161 vs 119; $p = 0.042$). Finally, the performance score obtained by the participants using STAR was 10% higher than the one achieved by participants using telestrator (81.9 vs 90.8; $p = 0.009$). Nonetheless, the results confirm the premise of the study: telementoring systems can be more effective if they provide some sort of feature that allows trainees to keep following surgical instruction even when the conditions are austere or even when a mentor is not readily available. Further studies should be done to ensure that this is true in an environment as austere as a battlefield, or even inside an operating room.

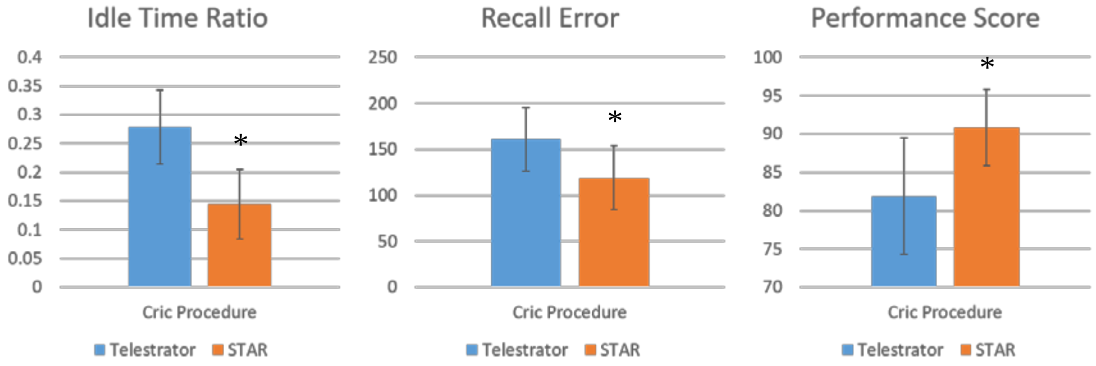


Figure 20. Visualization of future steps experiment results.

What opportunities for training and professional development has the project provided?
If the project was not intended to provide training and professional development opportunities or there is nothing significant to report during this reporting period, state "Nothing to Report."

Describe opportunities for training and professional development provided to anyone who worked on the project or anyone who was involved in the activities supported by the project. "Training" activities are those in which individuals with advanced professional skills and experience assist others in attaining greater proficiency. Training activities may include, for example, courses or one-on-one work with a mentor. "Professional development" activities result in increased knowledge or skill in one's area of expertise and may include workshops, conferences, seminars, study groups, and individual study. Include participation in conferences, workshops, and seminars not listed under major activities.

To achieve the Experimental Design 5 goals, the team conducted an experiment at Eskenazi Hospital. This experiment included the use of cadaveric specimens to performed lower-leg fasciotomies. The members of the team learned about various surgical techniques that they had never experienced before, broadening their knowledge about the domain. These experiences with healthcare elements are already helping those students that are willing to pursue a career in which some expertise of the healthcare domain in necessary.

Members of the team traveled to IEEE VR'18 to present the work to the virtual and augmented reality community. This conference provided a nice opportunity to network with other members of the scientific community that are using VR and AR to address problems of interest to the society. A couple of presentations had to do with using VR an AR headsets for healthcare applications, which provided a nice opportunity for the team members to exchange insights with these other teams about the challenges and positive aspects these systems have in healthcare.

Finally and as part of the goals set for rest of Phase 2, the team has been in contact with members from the Naval Medical Center Portsmouth (NMCP), where the Experimental Design 4 will take place. The team has learned valuable insights about how the system needs to be adapted in the context of military austere environments.

How were the results disseminated to communities of interest?
If there is nothing significant to report during this reporting period, state "Nothing to Report."

Describe how the results were disseminated to communities of interest. Include any outreach activities that were undertaken to reach members of communities who are not usually aware of these project activities, for the purpose of enhancing public understanding and increasing interest in learning and careers in science, technology, and the humanities.

Members of the Purdue team traveled to IEEE VR'18, held in Germany. Considering how strong the VR community is in Germany, this was a good opportunity to present the work to experts in the field of VR and AR. Very positive feedback was received, and insights regarding the future development that is scheduled for Phase 2 were obtained.

Several experts in the field of Human-Computer Interaction (e.g. Allison Okamura, Gregory Hager) visited the Purdue's team lab and received a demo of the STAR system. This helped to disseminate the work to experts and receive their valuable feedback, which is vital to the continuous improvement of the system.

What do you plan to do during the next reporting period to accomplish the goals?
If this is the final report, state "Nothing to Report."

Describe briefly what you plan to do during the next reporting period to accomplish the goals and objectives.

Task 3.1- Specialize the system to practice cricothyroidotomy on patient simulator
Implementation of a head-mounted, augmented reality telementoring platform
The current ARHMD-based system will be adapted to work in a fully austere scenario. The main change is that, instead of providing the Mentor System with a view of the operating field that is coming from a top-down camera, we will be leveraged the camera of the ARHMD to provide a first-person view of the operating field, from the mentee's point-of-view. The main challenge has to do with stabilizing the first-person view: the raw camera feed would not provide the mentors with an acceptable view to create surgical instructions.

Upgrade of the large-scale table-based interaction interface
To adapt the Mentor System to the new first-person view feed from the operating field, a new Unity-based framework will be introduced. This framework will include computer vision techniques and new rendering approaches to provide the mentors with a stable view to annotate the first-person view provided by the ARHMD Trainee System.

Experimental Design 4
The next experiment will take place at NMCP, were an austere environment will be simulated to evaluate the STAR platform. Details regarding to the design of the experiment need to be defined. In addition, the team members are planning on traveling to NMCP to perform a pilot study with a smaller population.

Rural assistance via top-down drone camera
While the communication between the drone and Mentor System is implemented, the goal for the drone is to broadcast a top-down view of the operating field for the remote expert to annotate. For that purpose, the relative pose of the drone in the operating field needs to be estimated continuously and transmitted to the ARHMD. We are exploring an initial e approach for this in which the drone would drop markers in the environment for autonomous pose estimation.

Task 4.1- Specialize the system for fasciotomy on a cadaveric leg
Experimental Design 5
Data analysis needs to be performed before reporting the results from this experiment. This analysis includes feedback from surgeons from IU regarding the definition of a weighted criterion for the IPS evaluation sections. After running this analysis, the results will be added to the ones we currently have.

Representing and visualizing an augmented version of the mentor arms and gestures

As an insight obtained from conducting the Experimental Design 5, expert surgeons communicated the interest on implementing a framework to transmit a 3D version of the mentor arms as they use the Mentor System. This way, for example, the mentor could point at a landmark of interest shown in the Mentor System's screen, and the mentee (wearing the ARHMD) could visualize a 3D version of the mentor arms, pointing at the landmark of interest. Initial development to achieve this feature has started as in planned to be completed by the end of Phase 2.

Acquisition of internal anatomical information via a portable ultrasound device
During the next period, the possibilities to transmit diagnostic images from a portable medical ultrasound to augment the mentee's view will be explored. Patient ultrasound information could be used as an additional diagnostic tool to provide both the mentor and the mentee with extra information as they operate.

4. **IMPACT:** Describe distinctive contributions, major accomplishments, innovations, successes, or any change in practice or behavior that has come about as a result of the project relative to:

What was the impact on the development of the principal discipline(s) of the project?
If there is nothing significant to report during this reporting period, state "Nothing to Report."

Describe how findings, results, techniques that were developed or extended, or other products from the project made an impact or are likely to make an impact on the base of knowledge, theory, and research in the principal disciplinary field(s) of the project. Summarize using language that an intelligent lay audience can understand (Scientific American style).

This technology will increase the sense of co-presence in the operating room between mentor and trainee. This is a fundamental step towards telexistence. Telexistence is a concept used to describe the framework that allows humans to have a real-time sensation of being and interacting with objects in places somewhere different from their actual location. The fundamental premise is that a higher sense of co-presence has an impact on the quality of mentorship. For example, by allowing the mentors to physically interact with the patient's anatomy though hand gestures (embodied interaction), the mentor's level of immersion and engagement will be significantly increased.

What was the impact on other disciplines?
If there is nothing significant to report during this reporting period, state "Nothing to Report."

Describe how the findings, results, or techniques that were developed or improved, or other products from the project made an impact or are likely to make an impact on other disciplines.

In this period, we completed the Experimental Design 5, which consisted on using the STAR platform to mentor surgery residents and medical students through a lower-leg fasciotomy procedure. The results found in this experiment will benefit the surgical community by providing a novel alternative to transfer surgical expertise remotely. In addition, the VR and AR community will benefit from this experiment, as demonstrating the usefulness of these techniques in the surgical domain is still an ongoing research topic.

What was the impact on technology transfer?
If there is nothing significant to report during this reporting period, state "Nothing to Report."

Describe ways in which the project made an impact, or is likely to make an impact, on commercial technology or public use, including:

- *transfer of results to entities in government or industry;*
- *instances where the research has led to the initiation of a start-up company; or*
- *adoption of new practices.*

We requested a temporal patent based on the concepts described on this report.

What was the impact on society beyond science and technology?
If there is nothing significant to report during this reporting period, state "Nothing to Report."

Describe how results from the project made an impact, or are likely to make an impact, beyond the bounds of science, engineering, and the academic world on areas such as:

- *improving public knowledge, attitudes, skills, and abilities;*
- *changing behavior, practices, decision making, policies (including regulatory policies), or social actions; or*
- *improving social, economic, civic, or environmental conditions.*

Currently the main instrument to improve surgical skills in trauma surgery requires animal models, one to one mentorship and lengthy and complex training sessions (e.g. the ATOM course attended by the PIs of this project). A more cost effective option that will make this training scalable consists of having the training surgeon teach the same ATOM class, remotely, through the STAR platform. This will allow residents (currently there are only 10-15 per class) to participate concurrently with only one mentor.

5. **CHANGES/PROBLEMS:** The Project Director/Principal Investigator (PD/PI) is reminded that the recipient organization is required to obtain prior written approval from the awarding agency Grants Officer whenever there are significant changes in the project or its direction. If not

previously reported in writing, provide the following additional information or state, “Nothing to Report,” if applicable:

Changes in approach and reasons for change
Describe any changes in approach during the reporting period and reasons for these changes. Remember that significant changes in objectives and scope require prior approval of the agency.

There were no significant changes in our approach during this period.

Actual or anticipated problems or delays and actions or plans to resolve them
Describe problems or delays encountered during the reporting period and actions or plans to resolve them.

No significant problems were found.

Changes that had a significant impact on expenditures
Describe changes during the reporting period that may have had a significant impact on expenditures, for example, delays in hiring staff or favorable developments that enable meeting objectives at less cost than anticipated.

No changes

Significant changes in use or care of human subjects, vertebrate animals, biohazards, and/or select agents
Describe significant deviations, unexpected outcomes, or changes in approved protocols for the use or care of human subjects, vertebrate animals, biohazards, and/or select agents during the reporting period. If required, were these changes approved by the applicable institution committee (or equivalent) and reported to the agency? Also specify the applicable Institutional Review Board/Institutional Animal Care and Use Committee approval dates.

Significant changes in use or care of human subjects

No changes

Significant changes in use or care of vertebrate animals.

No changes

Significant changes in use of biohazards and/or select agents

No changes

6. **PRODUCTS:** List any products resulting from the project during the reporting period. If there is nothing to report under a particular item, state "Nothing to Report."

- **Publications, conference papers, and presentations**
  Report only the major publication(s) resulting from the work under this award.

  Journal publications. *List peer-reviewed articles or papers appearing in scientific, technical, or professional journals. Identify for each publication: Author(s); title; journal; volume: year; page numbers; status of publication (published; accepted, awaiting publication; submitted, under review; other); acknowledgement of federal support (yes/no).*

1.
Title: Mixed Reality as a Medium for Improved Telementoring.
Journal: Military Medicine.
Authors: Edgar Rojas-Muñoz, Daniel Andersen, Maria Eugenia Cabrera, Voicu Popescu, Sherri Marley, Ben L. Zarzaur, Brian Mullis, Juan P. Wachs.
Status of Publication: Submitted. Under 1st revision.
Acknowledgment of federal support: yes.

2.
Title: Electrophysiological indicators of gesture perception.
Journal: International Journal of Psychophysiology
Authors: Maria Eugenia Cabrera, Keisha Novak, Dan Foti, Richard Voyles, Juan P. Wachs.
Status of Publication: Submitted. Under 1st revision.
Acknowledgment of federal support: yes.

3.
Title: Augmented Reality Future Step Visualization for Robust Surgical Telementoring.
Journal: Simulation in Healthcare
Authors: Daniel Andersen, Maria Eugenia Cabrera, Edgar Rojas-Muñoz, Voicu Popescu, Glebys Gonzalez, Brian Mullis, Sherri Marley, Ben Zarzaur, Juan P. Wachs.
Status of Publication: Submitted. Under 2nd revision.
Acknowledgment of federal support: yes.

4.
Title: Surgical Telementoring without Encumbrance: A Comparative Study of See-through Augmented Reality based Approaches.
Journal: Annals of Surgery.
Authors: Edgar Rojas-Muñoz, Maria Eugenia Cabrera, Daniel Andersen, Voicu Popescu, Sherri Marley, Brian Mullis, Ben Zarzaur, Juan P. Wachs.
Status of Publication: Published.
Acknowledgment of federal support: yes.

5.
Title: Teleproctoring with Mixed Reality: A Comparative Evaluation in the Context of Lower-Limb Fasciotomies.
Journal: Military Health System Research Symposium (MHSRS).
Authors: Juan Carvajal, Edgar Rojas-Muñoz, Maria Eugenia Cabrera, Daniel Andersen, Chengyuan Lin, Voicu Popescu, Brian Mullis, Sherri Marley, Ben L. Zarzaur, Juan P. Wachs.
Status of Publication: Submitted for oral presentation. Under 1st revision.
Acknowledgment of federal support: yes.

Books or other non-periodical, one-time publications. *Report any book, monograph, dissertation, abstract, or the like published as or in a separate publication, rather than a periodical or series. Include any significant publication in the proceedings of a one-time* *conference or in the report of a one-time study, commission, or the like. Identify for each one-time publication: Author(s); title; editor; title of collection, if applicable; bibliographic information; year; type of publication (e.g., book, thesis or dissertation); status of publication (published; accepted, awaiting publication; submitted, under review; other); acknowledgement of federal support (yes/no).*

Other publications, conference papers, and presentations. *Identify any other publications, conference papers and/or presentations not reported above. Specify the status of the publication as noted above. List presentations made during the last year (international, national, local societies, military meetings, etc.). Use an asterisk (*) if presentation produced a manuscript.*

1.
Title: A First-Person Mentee Second-Person Mentor AR Interface for Surgical Telementoring.
Conference: International Symposium on Mixed and Augmented Reality (ISMAR), 2018.
Authors: Chengyuan Lin, Daniel Andersen, Voicu Popescu, Maria Eugenia Cabrera, Edgar Rojas-Muñoz, Sherri Marley, Brian Mullis, Ben Zarzaur, Juan P. Wachs.
Status of Publication: Submitted. Under 1st review.
Acknowledgment of federal support: yes.

2.
Title: Augmented Visual Instruction for Surgical Practice and Training.
Conference: IEEE Virtual Reality and 3D User Interfaces, 2018.
Authors: Daniel Andersen, Chengyuan Lin, Voicu Popescu, Edgar Rojas-Muñoz, Maria Eugenia Cabrera, Brian Mullis, Ben Zarzaur, Sherri Marley, Juan P. Wachs.
Status of Publication: Published.
Acknowledgment of federal support: yes.

3.
Title: Biomechanical-based Approach to Data Augmentation for One-Shot Gesture Recognition
Conference: IEEE Automatic Face and Gesture Recognition, 2018.
Authors: Maria Eugenia Cabrera, Juan P. Wachs.
Status of Publication: Accepted.
Acknowledgment of federal support: yes.

4.
Title: Coherence in One-Shot Gesture Recognition for Human-Robot Interaction.
Conference: ACM/IEEE Human Robot Interaction, 2018.
Authors: Maria Eugenia Cabrera, Richard Voyles, Juan P. Wachs.
Status of Publication: Accepted.
Acknowledgment of federal support: yes.

5.
Title: What makes a gesture a gesture? Neural signatures involved in gesture recognition
Conference: IEEE Automatic Face and Gesture Recognition, 2017.
Authors: Maria Eugenia Cabrera, Keisha Novak, Dan Foti, Richard Voyles, Juan P. Wachs.
Status of Publication: Accepted.
Acknowledgment of federal support: yes.

6.
Title: One-Shot Gesture Recognition: One Step Towards Adaptive Learning
Conference: IEEE Automatic Face and Gesture Recognition, 2017.
Authors: Maria Eugenia Cabrera, Natalia Sanchez-Tamayo, Richard Voyles, Juan P. Wachs.
Status of Publication: Accepted.
Acknowledgment of federal support: yes.

- **Website(s) or other Internet site(s)**
  List the URL for any Internet site(s) that disseminates the results of the research activities. A short description of each site should be provided. It is not necessary to include the publications already specified above in this section.

Official project website, with overview of research, links to publications, images, and videos.

https://engineering.purdue.edu/starproj

- **Technologies or techniques**
  Identify technologies or techniques that resulted from the research activities. In addition to a description of the technologies or techniques, describe how they will be shared.

A telementoring system based on an Augmented Reality Head-Mounted Display was developed and validated with surgery residents and medical students as mentees, and general and orthopaedic surgeons as mentors. This approach leverages a novel technology to design a surgical telementoring system that creates immersive experiences without introducing additional encumbrance in the surgeons' working space. The work on this will technique will be presented at international conferences and through journal publications, and the openness of its code will be determined once the project is completed.

- **Inventions, patent applications, and/or licenses**

Identify inventions, patent applications with date, and/or licenses that have resulted from the research. State whether an application is provisional or non-provisional and indicate the application number. Submission of this information as part of an interim research performance progress report is not a substitute for any other invention reporting required under the terms and conditions of an award.

We filled a temporal patent with the prototype of the STAR system that we developed.

- **Other Products**
  Identify any other reportable outcomes that were developed under this project. Reportable outcomes are defined as a research result that is or relates to a product, scientific advance, or research tool that makes a meaningful contribution toward the understanding, prevention, diagnosis, prognosis, treatment, and/or rehabilitation of a disease, injury or condition, or to improve the quality of life. Examples include:
  - *data or databases;*
  - *biospecimen collections;*
  - *audio or video products;*
  - *software;*
  - *models;*
  - *educational aids or curricula;*
  - *instruments or equipment;*
  - *research material (e.g., Germplasm; cell lines, DNA probes, animal models);*
  - *clinical interventions;*
  - *new business creation; and*
  - *other.*

Databases, videos, raw images and recording of the ATOM sessions (3) are located at the PURR repository.

https://purr.purdue.edu/projects/starproject/files/

7. PARTICIPANTS & OTHER COLLABORATING ORGANIZATIONS

What individuals have worked on the project?

Provide the following information for: (1) PDs/PIs; and (2) each person who has worked at least one person month per year on the project during the reporting period, regardless of the source of compensation (a person month equals approximately 160 hours of effort). If information is unchanged from a previous submission, provide the name only and indicate "no change."

Example:

Name: Mary Smith
Project Role: Graduate Student
Researcher Identifier (e.g. ORCID ID): 1234567
Nearest person month worked: 5

Contribution to Project: Ms. Smith has performed work in the area of combined error-control and constrained coding.
Funding Support: The Ford Foundation (Complete only if the funding support is provided from other than this award).

Name: Juan P Wachs
Project Role: Principal Investigator
Researcher Identifier (e.g. ORCID ID): 0000-0002-6425-5745
Nearest person month worked: 1.12 month

Contribution to Project: Supervising the overall performance of the project. Coordinated visits to IUSM. Working with Maria Eugenia in all the aspects of gesture recognition and one shot learning. Working with Edgar Rojas for the design of the large interaction table. Working with Juan Carvajal for the design of drone system for rural environments. Helping with journal publications.

Name: Voicu Popescu
Project Role: Co-Investigator
Researcher Identifier (e.g. ORCID ID):
Nearest person month worked: 1.12 month

Contribution to Project: Actively participated in and advised research assistant Daniel Andersen and Chengyuan Lin in the research and development of the ARHMD system; in designing, conducting, and analyzing the results of user studies aimed at assessing STAR; in disseminating the project results in journal papers.

Name: Ben Zarzaur
Project Role: Co-Investigator
Researcher Identifier (e.g. ORCID ID):
Nearest person month worked: month

Contribution to Project:	*Dr. Zarzaur provided assistance regarding the Experimental Design 5. He acted both as a mentor and as an evaluator of the fasciotomies performed by the residents and medical students.*
Name:	*Brian Mullis*
Project Role:	*Co-Investigator*
Researcher Identifier (e.g. ORCID ID)*:*	
Nearest person month worked:	*month*
Contribution to Project:	*Dr. Mullis provided assistance regarding the Experimental Design 5. He acted both as a mentor and as an evaluator of the fasciotomies performed by the residents and medical students.*
Name:	*Sherry Marley*
Project Role:	*Co-Investigator*
Researcher Identifier (e.g. ORCID ID)*:*	
Nearest person month worked:	*month*
Contribution to Project:	*Helped the Purdue team with the Experimental Design 5 in aspects such as preparation of the facilities and participants recruitment. Coordinated visits to IUSM.*
Name:	*Kathryn Anderson*
Project Role:	*Co-Investigator*
Researcher Identifier (e.g. ORCID ID)*:*	
Nearest person month worked:	*month*
Contribution to Project:	*Helped the Purdue team with the Experimental Design 5 in aspects such as preparation of the facilities and participants recruitment. During the experiment, she assisted the participants throughout the procedure by handling them the surgical instruments, cleaning excess of blood in the cadavers, among other tasks.*
Name:	*Dan Andersen*
Project Role:	*Research Assistant*
Researcher Identifier (e.g. ORCID ID)*:*	
Nearest person month worked:	*5.25 months*
Contribution to Project:	*Description. Lead author on several publications related to the STAR platform. Researched and developed video streaming solution to transmit*

	imagery from the mentee site to the mentor site, as well as calibration data from the mentee top down camera to align coordinate systems.
Name:	*Maria Eugenia Cabrera*
Project Role:	*Research Assistant*
Researcher Identifier (e.g. ORCID ID):	
Nearest person month worked:	*5.25 months*
Contribution to Project:	*Maria Eugenia has lead research regarding one-shot gesture recognition leading several publications. She also has contributed in the design, execution and analysis of user studies. She has been one of the major contributors in the writing journal papers demonstrating the STAR platform.*
Name:	*Edgar Rojas*
Project Role:	*Research Assistant*
Researcher Identifier (e.g. ORCID ID):	
Nearest person month worked:	*5.25 months*
Contribution to Project:	*Edgar developed the mentoring system architecture together with the software and libraries required to interact with the large display. He has been one of the major contributors in the writing journal papers demonstrating the STAR platform.*
Name:	*Chengyuan Lin*
Project Role:	*Research Assistant*
Researcher Identifier (e.g. ORCID ID):	
Nearest person month worked:	*month*
Contribution to Project:	*Chengyuan developed the ARHMD-based Trainee System that calibrates and aligns itself with top down camera, and visualizes the annotations sent from the Mentor System.*
Name:	*Juan Andres Carvajal*
Project Role:	*Research Assistant*
Researcher Identifier (e.g. ORCID ID):	
Nearest person month worked:	*month*

Contribution to Project:	*Juan developed the communication between the drone and mentor system via TCP/IP and via WebRTC.*

Has there been a change in the active other support of the PD/PI(s) or senior/key personnel since the last reporting period?

If there is nothing significant to report during this reporting period, state "Nothing to Report."

If the active support has changed for the PD/PI(s) or senior/key personnel, then describe what the change has been. Changes may occur, for example, if a previously active grant has closed and/or if a previously pending grant is now active. Annotate this information so it is clear what has changed from the previous submission. Submission of other support information is not necessary for pending changes or for changes in the level of effort for active support reported previously. The awarding agency may require prior written approval if a change in active other support significantly impacts the effort on the project that is the subject of the project report.

Juan Wachs	09/01/2014 - 08/31/2017	0.23 SU 0.5 AY

University Of Denver

NSF: MRI Development: Human Avatars: Enabling Research in Natural Communication with Virtual Tutors, Therapists, and Robotic Companions

Major Goals of the Project: The goal of the proposed MRI development project is to develop a life-like emotive software/hardware instrument in the form of robotic character heads that will support natural spoken dialogs between the robot and a human that closely models the face-to-face communication behaviors of a sensitive and effective human tutor, clinician or caregiver to a degree unachievable with current instrumentation.

Overlap: No overlap.

Juan Wachs	09/5/2014 - 08/31/2019	0 SU 0 AY

NSF: Collaborative Research: I/UCRC for Robots and Sensors for the Human Wellbeing

Major Goals of the Project: The goal of the proposed center is to develop technology in the form of robots and sensors for assistive technologies to support therapies and rehabilitation of people with disabilities.

Overlap: No overlap.

Juan Wachs	04/1/2015 - 03/31/2016	0.12 SU 0.5 AY

THE NAVSUP FLEET LOGISTICS CENTER SAN DIEGO: An Efficient Real-Time Method for Detection and Characterization of UAVs

Major Goals of the Project: The research objective of this proposal is to develop a video-based methods for real-time detection of small, unmanned aerial vehicles (UAVs) leveraging on effective sense and avoid techniques. Such methods can be integrated into real-time on board processors. This, in turn, would lead to enhanced UAV's capabilities for detection of friendly and unfriendly airborne traffic and respond with appropriate alarms, maneuvers and notifications.

Overlap: No overlap.

What other organizations were involved as partners?

If there is nothing significant to report during this reporting period, state "Nothing to Report."

Describe partner organizations – academic institutions, other nonprofits, industrial or commercial firms, state or local governments, schools or school systems, or other organizations (foreign or domestic) – that were involved with the project. Partner organizations may have provided financial or in-kind support, supplied facilities or equipment, collaborated in the research, exchanged personnel, or otherwise contributed.
Provide the following information for each partnership:

Organization Name: Indiana University School of Medicine
Location of Organization: Indianapolis, USA
Partner's contribution to the project (identify one or more)

- *Experimental Design 5. The co-Investigators helped on the design of the fasciotomy experiment, provided the supplies and supported the completion of the experiment.*
- *In-kind support: they made available the surgical instruments and facilities to complete the Experimental Design 5.*
- *Collaboration: Dr. Zarzaur, Mrs. Marley and B. Mullis collaborated with the project staff on the project.*
- *Personnel exchanges: We visited IUSM for the Experimental Design 5 and the graduate students participated in the discussions and experiments.*

8. SPECIAL REPORTING REQUIREMENTS

COLLABORATIVE AWARDS: N/A

QUAD CHARTS: N/A

9. APPENDICES: N/A