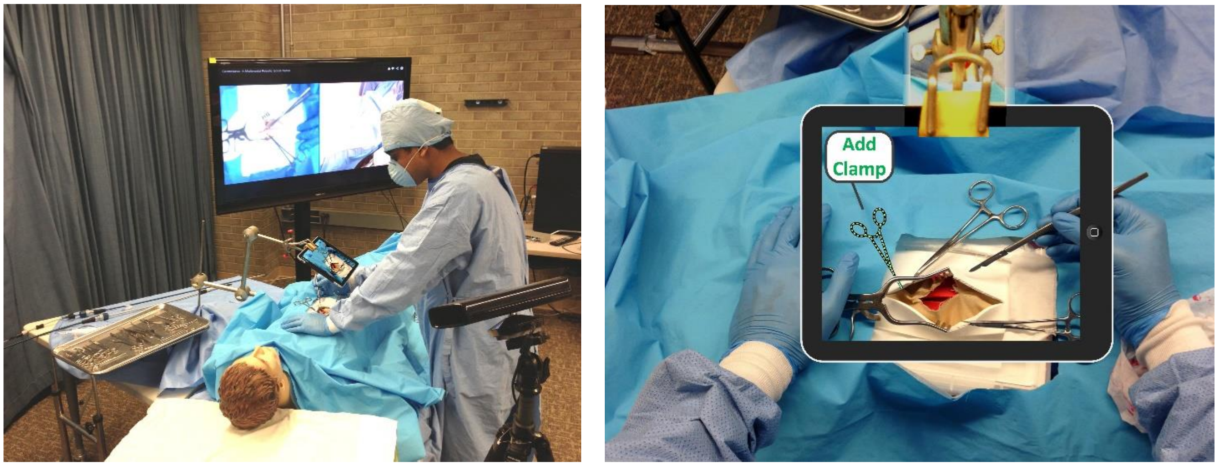

Figure 1: Concept illustration of augmented reality transparent display telementoring approach: overall view of trainee site (left), and trainee view (right).

Motivation. Surgical skills are specialized, and no surgeon has optimal skills in all possible procedures [1]. For this reason, systems that allow surgeons to be mentored during an operation by a remotely located expert surgeon are powerful tools. For example, a surgeon who develops a new surgical procedure can broaden the impact of that innovation by mentoring other surgeons from thousands of miles away. In urgent cases a general surgeon at a rural hospital with fewer trained resources can call upon the expertise of a specialist from a large urban health care center. In another example, an army trauma surgeon deployed at a forward operating base can refresh orthopedic trauma surgery skills under the mentorship of experts located in the United States.

Limitations of the state of the art. Current systems for surgery telementoring rely on telestrators, devices that allow a remote mentor surgeon to sketch instructional annotations on video or images from the trainee's operating field, displaying those sketches on a nearby monitor to help guide the trainee's actions. However, such systems require the trainee to repeatedly switch focus, looking back and forth between the monitor displaying the annotations and the operating field -- a distracting action that has been shown to substantially diminish telementoring efficacy and the trainee's surgical performance [2].

Intellectual merit. My goal is to research and develop a novel approach to surgery telementoring that integrates mentor annotations directly into the trainee's field of view of the operating field, through an augmented reality (AR) transparent display.

Figure 1 provides a concept illustration of the proposed approach. The trainee sees the operating field through a tablet *(left)*. The tablet simulates a transparent display by displaying the image the trainee would see in the absence of the tablet *(right)*. The images displayed on the tablet are sent to the mentor; the mentor annotates the images with graphical or textural information, such as indicating the precise location of a future incision line or of a surgical instrument (e.g. the clamp shown with a dotted line in Figure 1, right). The mentor's annotations are sent to the trainee and overlaid onto the transparent display to provide effective guidance. Realizing the proposed approach requires solving fundamental research problems related to transparent display simulation and annotation anchoring.

Potential advantages of proposed approach. First, the trainee surgeon does not need to shift focus between the operating field and another screen as in current telestrator systems; instead, the annotations appear directly in the trainee's view of the operating field. Second, the transparent display provides continuity between the part of the operating field seen by the trainee and the part seen through the display, preserving the natural hand-eye coordination on which surgeons rely.

Third, the approach only relies on a small number of compact commodity components, which enables deployment in resource-limited or austere environments.

Research plan: transparent display simulation. The transparent display is simulated on the opaque tablet by reprojecting the video acquired by the tablet to the trainee's viewpoint. This requires acquiring the geometry of the operating field, tracking the tablet, and tracking the trainee surgeon's point of view. Multiple possible solutions will be investigated. For operating field geometry acquisition, possible solutions include proxy geometric modeling by fitting a parameterized plane and incision contour model, depth acquisition from the tablet video stream, or depth acquisition with an external depth camera (e.g. Microsoft's Kinect). For tablet tracking, possible solutions include tracking using computer vision algorithms detect operating field features in the tablet video feed, and tracking based on the color and geometry of the operating field. For tracking the trainee's point of view, possible solutions include using the second (front-facing) camera on the tablet, or using external trackers such as depth camera trackers. I will also investigate bypassing the need to explicitly track the tablet and the trainee's point of view, by using an unobtrusive head-mounted camera (HMC) system (e.g. Google Glass) worn by the trainee. The HMC feed can be used to measure and eliminate misalignment between the parts of the operating field that are shown through the tablet and the parts that are observed directly.

Research plan: annotation anchoring. The annotations provided by the mentor must be anchored rigidly to their respective operating field elements as the tablet moves and as the geometry of the operating field changes. Some initial gains can be made by using existing feature-tracking and descriptor-matching algorithms, but most current tracking approaches assume surfaces that are rigid, planar, static, and largely unoccluded. None of these assumptions hold true for a surgical setting: skin and tissue stretch and deform, have significant depth differences, and change their shape as the surgeon makes incisions, and the surgeon's hands frequently occlude the field of view. Depth information found during geometry acquisition will be incorporated into the annotation tracking algorithms to improve tracking fidelity. Insights into simulation of deformable solids, such as cloth simulation, will be applied to this problem to further improve tracking of skin and tissue.

Evaluation. The approach will be evaluated through user studies that involve trainee and mentor surgeons to test the hypotheses that the approach leads to fewer focus shifts, and that fewer focus shifts correlates with improved surgical performance. I am part of a multidisciplinary team that includes trauma and orthopedic trauma surgery faculty from a teaching hospital in Indianapolis. The surgery faculty and residents are excited at the prospect of the AR transparent display telementoring system and they will help evaluate it.

Broader impacts. The project promises significant impact in many contexts. First, more effective surgical telementoring will magnify the ability of expert surgeons to share innovative and specialized knowledge to remote and disadvantaged areas. Second, the benefits of visual integration of live, sketch-based guidance afforded by the proposed approach will reach far beyond surgery to include virtually all educational and training contexts. Finally, the solutions to the fundamental research problems underlying transparent display and annotation anchoring will benefit not just telementoring, where a human expert annotates the real world, but all augmented reality applications, including those where automatically generated annotations help humans better understand the real world.

[1] Borman, K., et al. (2008). "Changing Demographics of Residents Choosing Fellowships: Longterm Data from The American Board of Surgery." J Am Coll Surg. 2008 May;206(5):782-8.
[2] Ereso, A., et al. (2010). "Live Transference of Surgical Subspecialty Skills Using Telerobotic Proctoring to Remote General Surgeons." J Am Coll Surg. 2010 Sep;211(3):400-11.