Mobile Augmented Reality for Distributed Healthcare

Point-of-View Sharing During Surgery

Lauren Aquino Shluzas, Gabriel Aldaz,
Joel Sadler, Shantanu Joshi, Larry Leifer
Center for Design Research, Stanford University
Stanford, California, USA
{larenino, zamfir, jsadler, joshi4, larry.leifer}@stanford.edu

David Pickham
Office of Transdisciplinary Research
Stanford Hospital & Clinics
Stanford, California, USA
dpickham@stanfordmed.org

***Abstract*—This research examines the capabilities and boundaries of a hands-free mobile augmented reality (AR) system for distributed healthcare. We use a developer version of the Google Glass head-mounted display to develop software applications to enable remote connectivity in the healthcare field; characterize system usage, data integration, and data visualization capabilities; and conduct a series of pilot studies involving medical scenarios. This paper presents the software development and experimental design for a pilot study that uses Glass for augmented point-of-view sharing during surgery. The intended impact of this research is to: (i) examine the use of technology for complex problem solving and clinical decision making within interdisciplinary healthcare teams; (ii) study the impact of enhanced visualization and auditory capabilities on team performance; and (iii) explore an AR system's ability to influence behavior change in situations requiring acute decision-making through interaction between centralized experts and point-of-impact delivery personnel.**

Keywords*—ambient; systems; distributed; healthcare; team-based collaboration; head-mounted display, surgery; wearable computing.

I. Introduction

In the healthcare field, the need for improved tools to enhance collaboration among patients and providers has become increasingly urgent – due, in large part, to a global rise in aging populations and chronic disease prevalence, coupled with increasing health care costs and physician shortages worldwide [1][2]. To address these challenges, this research examines the use of wearable mobile computing to mediate interdisciplinary communication and collaboration in healthcare. We first present an overview of collaborative technologies and interaction modalities for home-healthcare and hospital use. These advances in mobile computing provide remote patient monitoring, automate simple knowledge-base procedures, and facilitate the delivery of interventions. We then present the experimental design for a pilot study that uses augmented point-of-view (POV) sharing during surgery through leveraging the camera and integrated sensors of Google Glass' head mounted display (Figure 1).

A. Remote Patient Monitoring

For home healthcare applications, existing systems enable medical staff to remotely monitor patients suffering from advanced chronic disease and provide prompt support regarding health education and treatment compliance [3]. The *Vsee* video collaboration system (Sunnyvale, CA), for instance, simplifies patient-doctor interactions through web-based video calling, coupled with medical device integration.

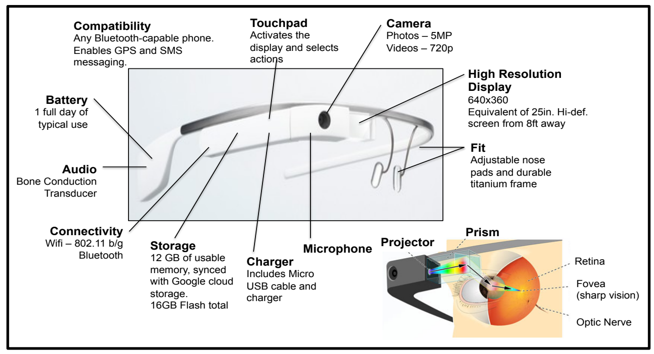

Figure 1. *Google Glass* (Mountain View, CA) wearable computer and head-mounted display features

In the consumer health and wellbeing space, a variety of products provide self-patient monitoring to encourage behavior modifications aimed at promoting healthier lifestyles. These include activity monitors such as the *Nike Fuelband* and *Fitbit Flex*, and the *LUMOback* real-time posture feedback system. Yet, despite current advances, home monitoring technologies are often limited by the dependency on appropriate bandwidth, customized networks and high-cost equipment, as well as a lack of integration into electronic medical record (EMR) systems.

In the hospital setting, remote monitoring systems, such as the *tele-ICU*, aid clinicians in the delivery of care to ICU patients. By collaborating with the bedside team, the *tele-ICU* support care without distraction, while assisting in the delivery of timely interventions [4]. Yet, financial barriers associated with installing and operating such systems has limited widespread adoption.

B. Automating Knowledge-based Procedures

For patient-virtual agent interaction, the animated virtual nurse (VN) is an automated system that teaches patients their post-discharge self-care regimen directly from their hospital beds [5]. This system incorporates a VN who embodies best practices in health communication for patients with inadequate health literacy, and illustrates a growing field in mobile computing aimed at increasing universal healthcare access.

 ISBN: 978-1-61208-356-8

Cognitive aids, such as dynamic checklists, present another example of tools to facilitate collaboration in the clinical setting, through automating knowledge-based procedures. A recent study involving dynamic checklists found that medical crisis care situations reveal "a physically complex information space, and relatively high-tempo time scales of gaze, action, and team-based coordination and communication" [6].

C. Facilitating the delivery of an intervention

Collaborative technologies that facilitate the delivery of an intervention may include those in which (i) a clinician (expert) aids a non-expert in delivering an intervention, and (ii) a clinician delivers an intervention remotely through a robotic interface. With the commercialization of high-speed data networks, the implementation of these scenarios may be realized through the use of augmented reality (AR) systems. Many AR applications provide the benefit of visualizing three-dimensional data captured from non-invasive sensors, and range from remote 3D image analysis to advanced telesurgery [7][8].

Despite existing technologies, however, there is a growing need for new tools capable of augmenting a clinician's knowledge base and his/her complex problem solving ability, while performing an intervention. Such augmentation can be accomplished if a system simultaneously connects the clinician (expert) to relevant medical databases, other experts, and a live telemetry of patients' relevant vital statistics. The first order challenge required to accomplish these connections is the ability to manage the resulting high-bandwidth information flow between human and computer agents, and to enable agents to collectively work as a design team.

In this paper, Section II describes the methods used to conduct this research study. In Section III, we provide an overview of point-of-view sharing during surgery, including software and hardware development, a usability assessment, and a proposed pilot study. Section IV provides a conclusion and discussion of future work.

II. METHODS

To address the challenges discussed above, this ongoing research effort examines the use of hands-free mobile AR for distributed healthcare collaboration. We hypothesize that a mobile AR system (head-mounted display) will shorten communication cycles and reduce errors associated with point-of-care decision-making and distributed collaboration in healthcare scenarios.

To test our hypothesis, we obtained four pairs of Google Glass as an initial platform for research. Our methodology includes: (i) clinical needs finding to ground the study in the context of high-impact clinical problems; (ii) software development to create customized applications for the head-mounted display that are specific to two or more clinical areas; and (iii) a series of pilot tests to characterize the AR system's usage, data integration, and data visualization capabilities in medical scenarios.

A. Clinical Needs Finding

We conducted needs finding at Stanford Hospital and Clinics from October to December 2013. Two members of the research team interviewed ten nurses and two physicians, and shadowed four additional nurses. Each interview lasted approximately one hour, and nurses were shadowed from one to three hours at a time. We recorded interviews using a digital recording device, and took hand-written notes during each interview and clinical observation.

From this process, we captured 135 clinical needs and grouped needs into 15 areas. To further narrow our research focus, we filtered needs based on degree of importance to the hospital, alignment with research interests, fit for Glass, and feasibility. We ordered our top three needs in order of increasing clinical risk. These included: (i) wound and skin care photography, (ii) point-of-view sharing during surgery, and (iii) vital sign communication when patients are suffering from cardiac arrest.

B. Initial Pilot Study

We developed a Google Glass application to capture and document images for chronic wound photography, using the Android 4.0.4 (API 15) SDK and Glass Development Kit (GDK) add-on. The application leverages Glass' camera, inertial measurement unit (IMU), infrared sensor, and microphone. The initial pilot study focused on the use of voice and gestural-based interaction commands for photo capture and documentation, and the transfer of annotated images to a patient's EMR. The software development and pilot study for wound care management have been separately documented [9]. In this paper, we focus on the software application development and experimental design for a second pilot study to conduct point-of-view sharing in the operating room, using Google Glass.

III. POINT-OF-VIEW SHARING DURING SURGERY

A range of studies has demonstrated the use of head-mounted cameras for clinical use and education. Bizzotto et al. [10], for instance, used the GoPro HERO3 in percutaneous, minimally invasive, and open surgeries with high image quality and resolution. Several reports document the live two-way broadcasts of patient surgeries by doctors wearing Glass in the operating room [11][12].

Figure 2. Center for Immersive and Simulation-based Learning

To build on existing work in this field, we plan to conduct a pilot study within Stanford's Center for Immersive and Simulation-based Learning (CISL), as shown in Figure 2. For this study, we will simulate a medical scenario using augmented POV sharing for the treatment of an acute condition, in which relevant patient data is superimposed on the Glass display, within the surgeon's field of view. The simulation will focus on complex problem solving with multiple potential solution paths (e.g., situations in which there is no optimal, context-independent solution).

A. *Software Development and Hardware Enhancement*

The development of a software application for POV sharing during surgery focuses on three key areas [13]: voice commands, bi-directional communication, and EMR data transfer. We intend to use voice commands to control the application in a hands-free manner, in order for clinicians to maintain heightened sterility while performing surgical procedures. Bi-directional communication is required to enable collaboration between surgeons wearing Glass and remote colleagues, and to establish connectivity with remote sensors in the healthcare environment. We are in the process of developing a communication interface between the wearable computer and remote sensors using WiFi and Bluetooth. Using an Arduino microprocessor as a proxy for medical sensors, we have demonstrated that wireless connectivity via WiFi may be achieved by connecting Glass to remote sensors through Android's WiFi Peer-to-Peer (P2P) API. For Glass, this may also be achieved through the Google Mirror API, as an intermediary. For Bluetooth connectivity, we demonstrated the ability to connect Glass with a remote sensor (Arduino microprocessor), pair the two devices, and transfer data between them. With Glass, the connection may be launched manually using the device's touch pad, physical gestures, or voice commands. We aim to apply the connectivity protocols, demonstrated with an Arduino, towards capturing the actual vital signs of patients from monitoring systems in the hospital (e.g., the Phillips Intellivue Solution System). We also intend to build on existing work in wound care photography to wirelessly transfer surgical image and video data to a patient's EMR [9].

Based on feedback from consulting surgeons, in addition to software development, we aim to physically enhance the Glass hardware for surgery in three ways. We intend to add a transparent splash shield that surgeons may adhere to the front frame of the Glass display for protection from infectious disease, attach an optical loupe to the frame (in front of a surgeon's left eye) in order to increase magnification for surgical procedures, and encase elements of the head-mounted display in a protective cover for improved cleaning and robustness during routine clinical use.

B. *Initial Feasibility and Usage Assessment*

Following software development and hardware enhancements, we will conduct an initial assessment of the AR system's ability to (i) connect with remote study participants, (ii) capture a patient's sensory data, and (iii) transmit information to/from a hypothetical EMR. We intend to evaluate the system's usage characteristics with 10-15 individuals as they wear the Glass technology while performing a series of manual tasks. We will evaluate each user's ability to: (i) use and navigate the system through voice and tactile commands, (ii) integrate multiple audio and visual data inputs, and (iii) transfer data. We will assess the time required for each user to complete a specified task, and the associated error rate.

C. *Pilot Study*

1) Experimental Set-up: In a pilot study at Stanford's CISL facility, an attending surgeon will wear the Glass head-mounted display, while conducting a hypothetical procedure in collaboration with one assisting surgeon and one nurse. The local medical team will be in direct communication with a remote team of collaborators (in Germany and the Netherlands) via the Glass interface. The team will be presented with a hypothetical medical scenario and asked to develop a solution in 20 minutes using standard operating room supplies. A 'patient', e.g., computer driven mannequin that replicates physiologic parameters (pulse, heart and breath sounds, blood pressure, etc.) – will be used in the simulation. The patient's sensory data will transmit to the remote team and to a hypothetical EMR, until the patient's desired health state is achieved during the simulation. Using voice commands, the attending surgeon will be able to switch views in the Glass display between EMR data and wound images with information overlays. The images within the Glass display will be projected on an adjacent wall, so that the assisting surgeons and nurse may see the procedure from the attending surgeon's point-of-view. A schematic illustration of the experimental set-up is shown in Figure 3.

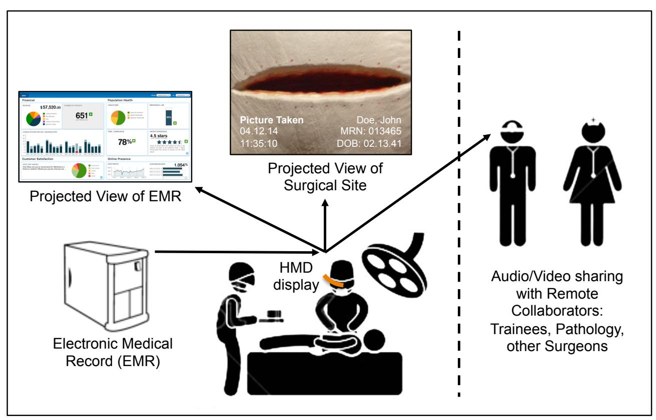

Figure 3. Point-of-View Sharing with Remote Collaborators

We will repeat the simulation three times with different medical teams. Local study participants will include registered nurses and medical residents from Stanford Hospital & Clinics.

2) Performance Measures: We plan to assess team performance using the AR system based on a combination of qualitative and quantitative measures. The independent variables, based on a Likert 5-point scale, include: X_1 – degree of team collaboration; X_2 – degree of task coordination (e.g., the ability to co-locate activity with visual instruction, and switch between data inputs and verbal communication modes); and X_3 – the degree of visual and auditory human perforance augmentation. The dependent variables include: Y_1 – the time for task completion and Y_2 the error rate in completing each task. Secondary measures include (i) the most/least effective mode to enhance feedback capability; (ii) the most/least effective data visualization display method; and (iii) each participant's percevied degree of user behavior change, based on the test conditions. Scores will be ascertained through a survey administered to study participants, field observations conducted by the research team, and post-experiment interviews with study participants.

3) Data Analysis Methods: We will calculate the mean time and survey scores for the three simulations. Multivariate statistical methods (e.g., ANOVA) will be used to determine if correlational relationships exist between the independent and dependent variables. Qualitative data, including field observations and interviews, will be transcribed, coded, and analyzed using NVivo qualitative analysis software.

IV. CONCLUSION AND FUTURE WORK

Augmented point-of-view sharing during operating room procedures advances the state-of-the-art in surgery through enhancing a clinician's knowledge base and decision-making capabilities, while performing surgical interventions. Specifically, since several individuals are needed to perform a surgical procedure (e.g., the attending surgeon, assisting surgeons, an anesthesiologist, and multiple nurses), the incision site is frequently crowded and obstructed from one's field-of-view. With augmented POV sharing, images projected from an attending surgeon's vantage point onto a remote screen provide visual clarity to individuals directly involved in the surgery, as well as remote participants and expert advisors. It also helps trainees and surgical fellows to learn procedures more accurately, by viewing an intervention from the same perspective as an attending surgeon, rather than from the reverse perspective (e.g., standing on the opposite side of the table) - which is often the case today. Finally, the use of POV sharing with bi-directional communication capabilities and remote sensor connectivity enables real-time collaboration with a pathology lab or expert consultants while performing a surgical intervention. Through visual overlays, POV sharing can co-locate one's visual field with information critical to performing a procedure – such as vital sign information, procedural descriptions, or MRI scans.

In the future, we aim to further enhance the robustness and reliability of a mobile AR system for acute care scenarios in the operating room and emergency room settings. This involves developing applications with data security and privacy features that are in compliance with strict hospital security protocols.

In the broader context of distributed collaboration for improved healthcare delivery, this research aims to examine the use of technology for complex distributed problem solving through interdisciplinary collaboration; gain an improved understanding of the benefits of human augmentation through enhanced visualization and auditory capabilities, on healthcare team performance; and explore an AR system's ability to influence behavior change in situations requiring acute decision-making through interaction between centralized experts and point-of-impact delivery personnel.

ACKNOWLEDGMENT

We gratefully acknowledge the Hasso Plattner Design Thinking Research Program (HPDTRP) for their support of this work. We thank the clinical staff at Stanford Hospital & Clinics for their time and participation in this research study.

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