Design Thinking in Health IT Systems Engineering: The Role of Wearable Mobile Computing for Distributed Care

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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 (HMD) to develop software applications to enable remote connectivity in the healthcare field, and to characterize system usage, data integration, and data visualization capabilities.

In this chapter, we summarize findings from the assessment of the SnapCap System for chronic wound photography. Through leveraging the sensor capabilities of Google Glass, SnapCap enables hands-free digital image capture, and the tagging and transfer of images to a patient's electronic medical record (EMR). In a pilot study with wound care nurses at Stanford Hospital ($n = 16$), we examined feature preferences for hands-free digital image capture and documentation; and compared SnapCap to the state of the art in digital wound care photography—the iphone-based Epic Haiku application.

The results of this study (1) illustrate the application of design thinking for healthcare delivery involving mobile wearable computing technology for distributed care, (2) improves our understanding of the benefits of human augmentation through enhanced visualization capabilities, and (3) explores a system's ability to influence behavior change through equipping clinicians with tools to improve complex problem solving and clinical decision-making in context-dependent medical scenarios. The work contributes to the future implementation of new features aimed at enhancing the documentation and assessment of chronic wounds, and provides insight into the need for future IT systems engineering projects aimed at enhancing healthcare connectivity for distributed care.

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1 Introduction

A collaborative approach to complex problem solving that leverages multiple points of view is fundamental to design thinking. 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 (Magnusson et al. 2004; Mattke et al. 2010).

To address these challenges, this research explores the application of design thinking in the field of health IT systems engineering, through the use of design collaboration technology for distributed care. In particular, we examine the use of wearable mobile computing to mediate cross-boundary communication and collaboration in the healthcare field.

This research documents the use of hands-free mobile AR for distributed healthcare and clinical decision-making. We used the Google Glass head-mounted display (HMD), which we were privileged to obtain through the Google Explorers Program. The Glass technology provides a platform for studying distributed design thinking in the healthcare field.

1.1 Prior Work

To narrow our research focus, we began needs finding at Stanford Health Care from October to December 2013. We interviewed and shadowed 16 clinicians to generate over 135 needs. We grouped needs into 15 broad clinical areas and ranked each category on a 5-point scale based on degree of importance to the hospital (pain point), alignment with research interests, and feasibility. Within the top ranking categories, we segmented needs by degree of clinical risk to patients. Our top three needs (in order of low to high patient risk) included: wound and skin care photography, point-of-view sharing during surgery, and vital sign communication during cardiac arrest (Aldaz et al. 2015; Aquino Shluzas et al. 2014). We selected chronic wound photography as a target focus area since: (1) a reduction in the incidence of chronic wounds—especially hospital-acquired pressure ulcers—is of paramount concern to healthcare facilities; (2) chronic wound image capture involves a relatively low degree of clinical risk for patients, thus enabling a solution to be tested and implemented quickly.

From a development perspective, we were interested in examining the usability features of a head-mounted display and the degree of clinical effectiveness that such a technology affords. We were also interested in examining the efficiency, satisfaction level, benefits and challenges associated with hands-free versus hands-on image capturing systems. We hypothesized that clinicians could successfully achieve their objective of hands-free digital photography through the use of a head-mounted display, controlled by gestural and voice-based commands; and that such a system could efficiently capture and document wound images, and transmit clinical data to a patient's EMR.

2 SnapCap System Design

The SnapCap System includes both a Google Glass application (known as "Glassware") and an Android smartphone application initially designed to be used by nurses for chronic wound photography (Aldaz et al. 2015; Shluzas et al. 2015). Google Glass was selected as an initial platform for research, since it has an optical head-mounted display that is capable of taking pictures and recording videos using an integrated camera. The device also has the ability to communicate wirelessly via WiFi and Bluetooth. Additional sensors integrated into the device enable the development of augmented reality-based applications. We developed the SnapCap Glassware using the Glass Development Kit (GDK) for Android 4.0.4 (API Level 15, Ice Cream Sandwich), and the smartphone app for Android 4.3 (API Level 18, Jelly Bean).

In the current implementation, an Android smartphone serves as a hypothetical EMR that includes a medical database for six fictional patients. The smartphone application communicates with Glass via Bluetooth. Presently, the Bluetooth link is unidirectional, from Glass to the smartphone application, because the app needs to store the images taken with the SnapCap Glassware as well as the associated tags. Speech-to-text conversion takes place on Google servers.

The present SnapCap architecture is for prototyping use only. Hospital implementation for routine clinical care would require encrypted communication channels and an interface with proprietary data storage to ensure privacy and security. Ultimately, we intend SnapCap to be platform-agnostic and compatible with a range of head mounted displays and EMR systems. (Complete details regarding the SnapCap system architecture are described in Aldaz et al. 2015.)

2.1 SnapCap Smartphone Application

The SnapCap smartphone application implements relevant features of the EMR, including a patient list, access to a patient database, and image storage in a media file. The password-protected application allows a clinician to select the name of the relevant patient prior to each patient encounter. The clinician can choose to either (1) take a clinical image, whereby the application establishes Bluetooth communication with Google Glass, or (2) view the patient's media file.

After choosing to take a clinical image, the nurse is free to place the Android smartphone in his or her pocket and put on Google Glass for the duration of the patient encounter. The photographs taken using Glass, along with the associated tags and voice annotations, immediately transfer via Bluetooth to the smartphone and are stored in the patient's media file, where they are available for viewing at any time.

2.2 SnapCap Glassware

The novel features of the SnapCap Glassware include (1) barcode scanning using the Glass camera, and tagging subsequent images with a patient's personal identification information that is embedded in the barcode, (2) capturing a live video preview in the Glass eyepiece before a photo is taken, (3) using a double blinking gesture to take photographs, through utilizing Glass' IR sensor, and (4) using a head tilt gesture (while in the preview mode) to zoom in and out of an image, and a head title gesture to send images to a patient's EMR, through the use of Glass' internal measurement unit (IMU) sensor.

3 Initial Usage and Feasibility Assessment

As an integral part of system development, in order to better understand how SnapCap might serve the wound documentation needs of nurses, we conducted an initial feasibility and usage assessment of the SnapCap System with five wound care nurses and two physicians at Stanford Health Care (n = 7 participants) (Aldaz et al. 2015). Each assessment consisted of two parts and lasted approximately one hour. First, we reviewed the Google Glass navigation basics with each participant. We then asked each participant to complete a series of tasks in order for the research team to qualitatively evaluate the operation of Google Glass, and users' preferences toward new and existing Glass features. The tasks included:

1. Using voice and touch-based commands to take a picture and record a video, using Glass's standard features (without image preview and zooming).
2. Evaluating the use of a customized camera zoom application, with image preview, that allowed users to zoom in and out through blinking one or both eyes in rapid succession.
3. Assessing the use of the customized camera zoom application with image preview, to zoom in and out through a one-finger gesture (sliding one's finger back and forth on the Glass touch pad).
4. Evaluating the use of Glass's existing historical image retrieval feature, in which users scroll forward on the Glass touchpad to see a list of previously taken images.

In the second part of the assessment, we asked clinicians to answer six, multipart questions regarding their preferred methods for capturing, cropping, annotating and retrieving wound images, along with considerations for sterile image capture techniques.

From this qualitative assessment, we learned that mobile, hands-free operation was critical for wound image capture and annotation. None of the clinicians wanted to touch a head-mounted image capture system with potentially contaminated gloves. We also learned that, as a baseline functionality requirement, the new system must perform as well as the current Epic Haiku digital image application, which is the current state of the art in wound photography at Stanford Health Care (Aldaz et al. 2015). Based on lessons learned from the initial feasibility assessment, we revised the SnapCap Glassware design with modifications and customized features, to address users' needs before conducting the wound care pilot study.

4 Pilot Study: Image Capture and Documentation

We conducted a two-part within-subjects lab-based pilot study with 16 nurses from Stanford Health Care (15 female, 1 male; 11.7 ± 8.7 years of wound care experience). The first part focused on an evaluation of core features of the SnapCap System and a comparison between the use of SnapCap and the current state of the art in digital wound care photography, the iPhone-based Epic Haiku application. The second part of the pilot study involved collecting and analyzing speech-to-text data for wound annotations (Aldaz et al. 2015).

We conducted a lab-based pilot study with hypothetical patients in order to focus on user interaction preferences for digital image capture and documentation, and to ensure that each nurse captured the same images, as a means of direct comparison between the two applications for wound photography. Study participants were recruited from a group of wound and ostomy care nurses at Stanford Health Care. None of the nurses had prior Google Glass experience. All 16 nurses had prior smartphone experience, while three nurses had worked directly with Epic Haiku.

4.1 Part 1: SnapCap Feature Evaluation and Application Comparison

For part one of the evaluation, we brought each nurse into a hospital room where we had placed two pelvis-only mannequins and an identifying barcode on a table. The mannequins are normally used to train students in the assessment and treatment of pressure ulcer wounds. A researcher explained the purpose of the study, the time breakdown per user session, the Glass navigation basics, and the experimental set-up. A researcher explained the use of both SnapCap and Epic Haiku, and asked each nurse to photograph a wound on a mannequin using (1) SnapCap (running on Glass and a Galaxy Nexus smartphone) and (2) Epic Haiku (running on an iPhone 4S). The photographs taken by nurses (using SnapCap) were saved in the patient's hypothetical EMR in order to examine the quality of each photo taken.

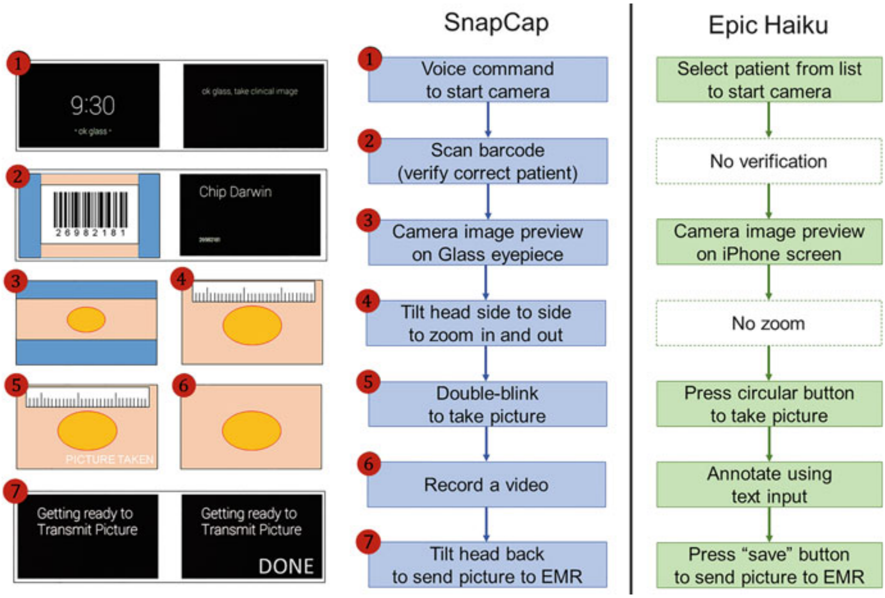

Fig. 1 Wound photography flow for SnapCap (*left*) and Epic Haiku (*right*) (Aldaz et al. 2015)

For wound annotation, each nurse was asked to use text-based documentation in Epic (per standard documentation practices) and to annotate the wound in a 10-s video recording using the SnapCap system. Figure 1 shows the step-by-step flow in each session. The research team took manual notes and recorded each session using a digital recording device. Photographs and brief videos of nurses using the SnapCap System and Epic Haiku application were also captured. Each user session, consisting of the SnapCap evaluation, application comparison, and a post-task questionnaire, lasted 30–45 min per participant.

4.2 *Part 1: Post-task Questionnaire*

Following the use of each system, participants completed a pen-and-paper questionnaire that was segmented into five areas. The questionnaire first asked users to provide their number of years of wound care experience and smart phone experience, and to list mobile applications that they commonly use. The questionnaire then asked participants to share their preferences for (1) current SnapCap system features, (2) application preferences for SnapCap versus Epic Haiku, and (3) preferences for the implementation of future SnapCap features. The research team saved the questionnaire data in an Excel spreadsheet for data analysis.

Glass Feature Preferences In the first part of the post-task survey, participants were asked to indicate their preference for the following SnapCap features:

1. Barcode scanning for patient identification
2. Voice-based documentation via a brief video recording
3. Double blinking gesture to take photographs
4. Head tilt gesture for zooming in and out of an image

Response options were prefer, do not prefer, or recommended improvements (with space to provide improvement recommendations). For each question, a response was required and multiple response options could be selected.

Application Preferences In the second part of the post-task survey, participants were asked to indicate their preference between SnapCap and Epic Haiku for the following performance dimensions:

1. Considerations for sterile wound image capture technique
2. Photo-capture capability
3. Image quality
4. Overall Ease of Use

Response options were Epic Haiku, Google Glass, no difference, and neither. For each question, a single response was required.

Preferences for Future SnapCap Features In the third part of the post-task survey, participants were asked to indicate their preferences regarding the perceived benefit of future SnapCap features:

Response options were yes, no, and no preference. For each question, a single response was required.

4.3 Part 2: Speech-to-Text Wound Annotation

Following the initial user session, we conducted a 10–15 min follow-up session at Stanford Health Care with the original 16 nurse participants, to obtain quantitative data on the performance of Google's speech-to-text (STT) engine. In these sessions, we asked each nurse to read aloud a wound annotation, consisting of two fictitious descriptions, while wearing the Glass head-mounted display. For example:

> This is a stage 3 pressure ulcer, measuring 11 centimeters by 6 centimeters by 3.4 centimeters deep, full-thickness ulceration which probes to bone, circumferential undermining, 2.5 centimeters at 12 o'clock and 0.2 centimeters at 6 o'clock.

Results of the transcription were stored locally in Glass' built-in memory for analysis.

5 Results

For the SnapCap feature evaluation and application comparison (Part 1 of the pilot study), we used the Wilcoxon Signed-ranks test, a non-parametric statistical hypothesis test, to evaluate differences in mean ranks between two response options. The analysis was conducted using IBM SPSS statistical software. The details (data analysis and complete results) can be found in Aldaz et al. (2015).

6 SnapCap System Evaluation: Hands-Free Digital Image Capture and Documentation

We evaluated nurse preferences for features and interactions aimed at enhancing digital image capture and documentation. These included: barcode scanning, voice-based documentation through video, double blinking, and head tilt. Figure 2 illustrates the difference between the sum of ranks for feature preferences. In a follow-up study, we examined the accuracy of Google's STT engine for wound documentation.

6.1 Barcode Scanning for Patient Identification

A Wilcoxon Signed-ranks test indicated that there was a statistically significant preference for hands-free barcode scanning for routine clinical care, $Z(15) = -3.873$, $p < 0.001$, $r = 0.71$. All 16 nurses successfully used the SnapCap Glassware to read the patient barcode within 4 s. One nurse indicated that, "Google Glass has the ability to barcode patient identity to reduce errors."

6.2 Voice-Based Documentation Through Video

The data analysis indicated that voice-based documentation through a brief video recording was strongly preferred by nurses, $Z(15) = -2.84$, $p = 0.005$, $r = 0.52$. The qualitative data also indicated that nurses favored the use of voice commands for launching the video recording and image capture features of the SnapCap System. However, the data revealed that current voice-commands were challenging for participants to use. Diverse failure modes included saying an incorrect phrase (3 nurses), saying a phrase too quickly (1 nurse), or saying a phrase too softly (1 nurse). While documenting a wound through a verbally annotated video, nurses frequently commented that the 10-s duration was too short, and that additional time was required.

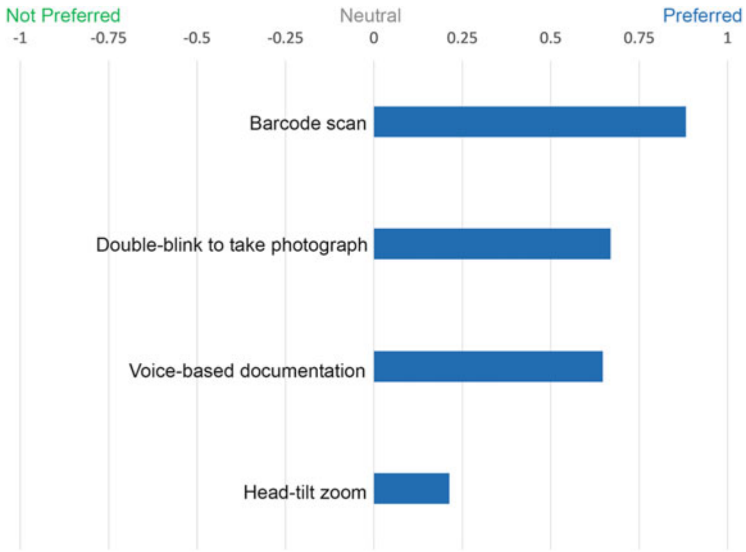

Fig. 2 Normalized difference between the sum of ranks for SnapCap feature preferences (Aldaz et al. 2015)

6.3 Double Blinking to Take Photographs

Nurses took a photograph (made the camera shutter open and close) by double blinking. Overall, double blinking was well received, with a statistically significant preference for this feature, $Z(13) = -3.606$, $p < 0.001$, $r = 0.71$. One nurse took five or six photographs inadvertently because Google Glass registered her natural eye-blinking rate as double blinking. Another cautioned that double blinking "may be too variable depending on the individual."

6.4 Head Tilt for Zooming

Nurses achieved camera zoom in and out by tilting their head to the right and left, respectively. Overall, this was the least preferred hands-free interaction method, $Z(10) = -1.897$, $p = 0.058$, $r = 0.42$. One nurse commented that the zoom was slow to respond, and three more indicated that this feature might interfere with their ability to assess wounds or pressure ulcers (for example on the back or the heel), which usually required them to tilt their heads from side to side. They felt that seeing the image zoom in and out on the eyepiece display could potentially interfere with their ability to take a high quality photograph.

6.5 Speech-to-Text Annotation

When we presented nurses with the possibility of annotating a wound through speech-to-text transcription, they were generally excited about this feature, but anticipated having to access the text for review and editing if necessary. From data gathered during the follow-up user session, we evaluated the performance of the Google speech-to-text (STT) engine for transcribing wound annotations. Due to technical issues, 2 of the 16 annotations had missing data—in each case, several words were missing from the transcript. Additionally, we noticed three instances when a nurse uttered an incorrect word, so we removed these words from the data set.

To analyze the Google speech-to-text (STT) data, captured in the follow-up user sessions, we used Word Error Rate (WER) as a standard measure for examining transcription accuracy (Jurafsky and Martin 2014). The overall WER of Google's STT for the fictitious wound description, among the 16 annotations evaluated, was 21.9 %. For individual nurses, the WER ranged from 7 to 38 % (SD = 10.3 %). From a technical standpoint, the Google STT performed well, in conjunction with the Glass hardware, in a majority of the tests. Fourteen out of sixteen (87.5 %) nurses successfully saved the two wound annotations in four attempts or less (although examination of the text files revealed a small amount of missing data on 2 of the 14 data files). Two of sixteen nurses (12.5 %), however, required more than ten attempts to successfully save the two wound annotations. In both cases, the problem with saving annotations were due to poor network connectivity, which caused the program to hang-up in mid-transcription (Aldaz et al. 2015).

7 Comparison Between SnapCap and Epic Haiku

We compared the SnapCap System and Epic Haiku for digital wound photography. Four aspects we investigated were: (1) sterile image capture technique, (2) photo capture capability, (3) image quality, and (4) overall ease of use. Figure 3 shows the difference between the sum of ranks for application preferences.

7.1 Sterile Image Capture Technique

A Wilcoxon Signed-ranks test indicated that there was a statistically significant preference for the Glass SnapCap System versus Epic Haiku in regard to sterile image capture technique when photographing wounds, $Z(16) = -3.873$, $p < 0.001$, $r = 0.68$. Comments relating to the SnapCap system included: "Much better experience," and "Not keen on touching the Glass frame with gloved hands during a consult."

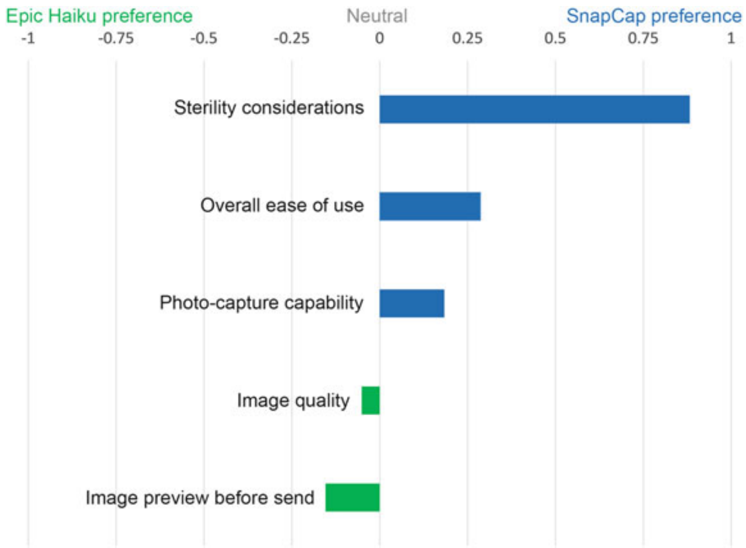

Fig. 3 Normalized difference between the sum of ranks for application preferences (Aldaz et al. 2015)

7.2 Photo Capture Capability

The data analysis revealed that there was no significant difference in preferences between the Glass SnapCap system and Epic Haiku for photo capture capability, $Z(16) = -1.667$, $p = 0.096$, $r = 0.29$. Although, qualitative data illustrate that nurses preferred to preview images on a relatively large iPhone screen, as opposed to the smaller Glass display. One nurse commented, “Google Glass has the ability to barcode patient identity to reduce errors, but needs better pixel definition.”

7.3 Image Quality

There was no significant difference in preferences between the image quality of the SnapCap System and Epic Haiku, $Z(15) = -0.816$, $p = 0.414$, $r = 0.15$. Nurses agreed that the quality of photographs taken should be sufficient for making clinical decisions, and qualitatively perceived image quality as a weakness of SnapCap. Using SnapCap, the 16 nurses transmitted 30 wound photographs from Glass to the smartphone app, of which we considered 17 of 30 (56.7 %) to be of acceptable quality for clinical use. Challenges included blurred (7/30, 23.3 %), tilted (3/30, 10 %), and improperly framed (3/30, 10 %) photos.

7.4 Overall Ease of Use

The data illustrate no significant difference in preferences between the SnapCap system and Epic Haiku in terms of ease of use, $Z(14) = -1.732$, $p = 0.083$, $r = 0.33$. Given the lack of familiarity that the nurses had with head-mounted displays, we see the limited difference in ease of use preferences as an encouraging result. One nurse commented that, "Epic Haiku is more 'normal' for today's registered nurses, but Google Glass has some great possibilities." Another nurse called using SnapCap for wound photography, "a much better experience" then Epic Haiku.

8 Preferences for Future Image and Data Sharing Features

The survey data captured user preferences regarding potential new features for improved image and data sharing, for digital wound care photography. These include the use of a head-mounted display (HMD) for bi-directional communication with colleagues, features for historical image retrieval for data recall and sharing, and the use of a dynamic digital ruler inside the eyepiece of an HMD.

8.1 Use of a Head-Mounted Display to Share and Discuss Images

A Wilcoxon Signed-ranks test indicated that there was a statistically significant preference for the future use of head-mounted displays for sharing and discussing wound images among colleagues, in order to obtain real-time feedback on a diagnosis or to aid in clinical decision-making, $Z(13) = -3.606$, $p < 0.001$, $r = 0.71$. One nurse commented that she felt such a system was, "an interesting idea" and another mentioned, "it is a definite possibility."

8.2 Historical Image Retrieval for Data Recall and Sharing

The data illustrate a significant preference for historical image retrieval, to achieve time-lapse image recall in a head-mounted display after taking a series of photographs, $Z(14) = -3.742$, $p < 0.001$, $r = 0.71$. Suggested uses for this feature included the ability to see changes in wound margins over time, and to track a wound's staging and healing progression (for stage 4 to stage 1 pressure ulcers). One nurse commented that it "would show progression or deterioration of the wound." Another mentioned, "this is very important for staging pressure ulcers—one must know the previous stage so one does not downstage the ulcer."

8.3 Dynamic Digital Ruler Inside the Glass Eyepiece

The data revealed a significant preference for a digital ruler inside the eyepiece of a head-mounted display, to replace a hand-held paper ruler, $Z(13) = -3.051$, $p = 0.002$, $r = 0.60$. Comments included: "Need to work on accuracy, but yes, that would be great so that you wouldn't have to hold or dispose of the ruler," and "Huge help!"

9 Conclusion

SnapCap enables hands-free digital photography, tagging, speech-to-text image annotation, and the transfer of data to an electronic medical record. In its current implementation, SnapCap leverages Google Glass' camera and internal sensors to guide clinicians through the process of taking and annotating wound images. This book chapter documents the SnapCap architecture and examines user preferences regarding hands-free (voice and gesture-based) interactions for image capture and documentation, based on a pilot study with sixteen wound care nurses at Stanford Health Care. We compare the SnapCap Glass application with the current state of the art in digital wound care photography.

The data illustrate that nurses strongly favored SnapCap's ability to rapidly identify patients through barcode scanning. They also favored the use of voice-based commands to launch applications and to document wounds, as well as the double blinking action to take photographs. However, users expressed mixed views regarding head tilt gestures for zooming while previewing images. In a head-to-head comparison with the iPhone-based Epic Haiku application, users strongly preferred the SnapCap System for sterile image capture technique when photographing wounds. Yet, preferences were divided in regard to photo capture capability, image quality, and overall ease of use. The similar ease of use scores for the SnapCap and Epic Haiku systems was promising, given the lack of prior experience that nurses had with head-mounted displays in comparison to smartphones.

In considering future research directions, this work reveals that clinicians need a hands-free, rapid, convenient, and affordable device that provides wound measurements with a reasonable level of reliability and repeatability. Such a system would help to address the growing problem of chronic wounds—which affect 6.5 million Americans and pose a $25 billion annual financial burden to the U.S. health care system. A repeated wound measurement system would be a vital component of overall chronic wound assessment (for pressure ulcers in particular), as it provides an indicator of the percent reduction or increase in wound area over time.

The research summarized in this chapter provides a foundation for the development of new integrated applications for the capture, tagging, and transfer of digital images for wound care and other clinical applications. This work illustrates the application of design thinking for healthcare delivery that involves mobile wearable computing technology for distributed care. By using the design and evaluation of technology as a platform for research, this work improves our understanding of the benefits of human augmentation through enhanced visualization capabilities. It explores a system's ability to influence behavior change through equipping clinicians with tools to improve complex problem solving and clinical decision-making in context-dependent medical scenarios.

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