Using Virtual Reality to Study Health in the Home

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ABSTRACT

Managing one's own healthcare has been progressively changing from occurring at hospitals and healthcare facilities to one's own day–to–day living environment. Due to this change, studying how people care for themselves becomes more challenging as visiting people in their living environments is intrusive and often logistically challenging. LiDAR scanning technology allows for highly detailed capture and generation of 3D models. With proper rendering software, virtual reality (VR) technology enables the display of LiDAR models in a manner that provides immersion and presence of feeling like one is situated in a scanned model. This document describes the combination of using LiDAR and VR technology to enable the study of health in the home. A research project involving the study of how home context affects diabetic patients' ability to manage their health information in the home is presented as an example. The document finishes by discussing other potential health care applications that could use similar methodologies as those introduced to improve health in the home for additional chronically ill populations.

Index Terms: Human-centered computing—Human computer interaction (HCI)—Interaction paradigms—Virtual reality

Figure 1: Immersed participant tagging items inside of a virtual representation of a physical kitchen.

1 INTRODUCTION

Health and healthcare are practices that often are thought to happen in hospitals and healthcare facilities. However, there is growing evidence that the home environment plays a critical role in the health and well-being for individuals. Unlike clinical environments, homes are far less standardized than institutional settings, are idiosyncratic and can be cluttered and chaotic. Studying home environments is extremely difficult for a variety of reasons. First, creating an artificial testing environment is difficult as the clutter and chaos in the environment will be artificial. On the other hand, testing in a real environment is difficult as real environments are constantly changing. In addition, bringing in participants to evaluate real environments can be intrusive and it may be difficult to maintain the home owners privacy. Finally, bringing subjects to an actual home may be challenged by both temporal and transportation logistics.

The ongoing migration of health care from the institution to the home and the concomitant rise in consumer health technologies calls for new ways to better characterize how this residential context of care shapes individuals' health information needs and their abilities to meet them. Active patient participation in health promotion and disease prevention is recognized as essential to accomplishing the goals of Healthy People 2020 [21]. There is over twenty years' of evidence of the positive outcomes when lay people use computer systems for personal health information management (PHIM) [2–6, 10, 13–15]. However, there is growing evidence that better understanding of the household context where these technologies are being used might lead to both clarification of the health information management challenges faced in the home and improved design of the technologies intended to be used there [1, 22].

There are over twenty years of calls for more systematic study of interior home environments, yet little progress has been made. Home assessment is difficult because the spaces are highly personal and therefore do not lend themselves to the same type of context assessments applied in formal work environments [23]. Certain features, like the visibility of a calendar or the proximity of a glucometer to the computer that receives its blue-tooth signal to upload a reading, can only be discerned by visual assessment. Yet home assessment is time consuming [9] and often requires experts [19], particularly when the focus of the assessment is modifications needed to assure accessibility of a home [26]. Additionally it is not clear which aspects of the house are important to examine to promote understanding of PHIM in the home context.

Over the past twenty five years, LiDAR scanning has emerged as a fascinating technology that allows for the rapid acquisition of three dimensional data of real world environments [8]. LiDAR scanning results in data known as a "point cloud", which is normally represented as an unstructured list of 3D positions with optional color and normal data per point. While LiDAR scanning has been utilized in such diverse applications as archaeology, geology, and cultural heritage [18, 24, 25], the capture of the home environment has seen less research interest [7, 27, 28]. Terrestrial LiDAR scanners now operate at a fast enough rate where it is possible to scan the inside of a patient's home environment in a relatively short period of time (two to four hours, depending on the size of the home). By combining the ability of LiDAR technology to scan and model interior home environments, with VR technology to display these models in a CAVE [12] or head mounted display, it is now possible to systematically study home environments to better understand how home context affects one's ability to manage health in the home.

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2 METHODS

The following subsections describe a methodology developed that incorporates the use of LiDAR and VR on an active federally funded research project to study health in the home of persons with self-reported diabetes. Community-dwelling adults who self-report as having diabetes were chosen for this exploratory study because management of diabetes is both information intensive and requires self-care tasks. Although the disease manifests differently in different people, people with either Type 1 or Type 2 diabetes share a number of information and self-care tasks (e.g. test blood glucose level, determine how much insulin or hypoglycemic medication to self-administer, recall clinician guidance regarding activity/food balance). Each of these tasks has associated PHIM components (e.g. recording and communicating blood glucose, retrieving and applying decision rules, storing pamphlets provided by clinician). The physical layout of the house can affect the performance of PHIM for the person with diabetes – spaces may or may not afford privacy for self-monitoring, visible memory aids like charts can assist in blood testing and insulin management, and file drawers can hold pamphlets. While it is long-recognized that health behaviors result from a complex interplay between people and their environments [17], developments in computer technology, specifically VR, now afford a safe and efficient way to apply intense scrutiny to this interplay in the household context. The research project seeks to answer two questions:

1. Which features of the home context shape PHIM?

2. To what extent do task factors and personal characteristics alter the influence of household context on PHIM?

The active research project consists of five separate phases, described in the following subsections, that define the methodology used for studying PHIM of patients with diabetes.

2.1 Environment Capture and Interview

In the first phase, the research team conducted in-depth interviews and in-home assessments through 3D image capture of twenty homes of resident informants managing diabetes. The aims of the semi-structured interviews were to explore participants' PHIM strategies and to contextualize these strategies within the home. The intensive assessments of the physical environments were accomplished using LiDAR. A typical point-cloud of a full home totaled 500,000 million to 1 billion points and took between two and five hours to capture. Internally developed point-cloud processing and visualization applications of the LiDAR data allowed for display within a six-sided CAVE VR display environment. Immersive visualization of such models allows a user to feel physically located in the home environment. Since the model is 3D, and not a 360-degree photograph, users can virtually move anywhere they want throughout the home using a tracked 6-DOF wand device. This combination of technologies allows us to study elements of PHIM in real home environments in a novel, efficient, and less intrusive manner.

The twenty homes were not modified to accommodate any chronic illness or disability; participants were asked not to change or 'prepare' their homes for scanning visits. Thus, these scans generated a reference set of twenty virtual 3D households while retaining their innate, personal ambiance and varying levels of clutter. In-depth interviews with home occupants resulted in a catalog of PHIM tasks performed in each of the twenty houses. These tasks centered on medication management, self-monitoring, and general information management. This reference set of virtual homes enabled experts and lay participants to perform home assessments in a VR CAVE. In the ensuing phases two through four, expert and lay participants alike navigated through the virtual homes to identify features - household objects and spaces - that could impact PHIM done by the occupant.

2.2 Expert VR Home Assessment

During the second phase of the project, six experts in industrial engineering, health informatics, computer science, and nursing viewed sixteen virtual homes that represented the four targeted home types (detached, semi-detached, multi-unit, and mobile). The experts were allowed a maximum of fifteen minutes to walk through each home, using the lab's VR CAVE, and select items using a tracked 6-DOF wand input device, to "tag" items, that they believed would either facilitate or inhibit performance of specific PHIM tasks.

In the VR application, the wand acted as an interactive, virtual highlighter, enabling our participants to visually and virtually tag anything within the point cloud model of the home that related to PHIM. As the user aimed the tracked wand within the CAVE, a small sphere appeared at the end of the wand at the point of intersection with the point cloud model. Pressing a button on the wand created a yellow tint at the area of intersection. These individual selections (tags) were then saved upon ending the CAVE application. Figure 1 shows an immersed user selecting an area of a kitchen model.

Group debriefing sessions were held with the expert participants after each week of data collection. The combined tags created by different experts tagging at different times in a single home were overlaid to produce a heat map of tagged features in rooms. Each expert's tags were assigned a different primary color, so that when tags overlapped, a combination of the two viewers' colors was generated (e.g. red + yellow = orange). As a group, experts viewed these heat maps and then identified both objects and spaces in the home that were found to be commonly tagged. This process resulted in a cumulative list of features, both objects (for example, nightstand) and spaces (kitchen), that were all confirmed by group consensus. A master grid was then created in Excel of all valid tags generated by the expert participants in each virtual home. Valid tags are defined as those that were not reported as errors during the debriefing sessions. Overall, 68 unique objects were tagged, including expected objects such as calendars, clocks, and computers, as well as more surprising objects such as televisions, photographs and stairs.

2.3 Laypersons VR Home Assessment

A similar process was followed with twenty lay participants, all of whom reported being told they have diabetes. These lay participants were asked to consider how they would manage PHIM tasks in each of the two virtual homes they viewed. Specific PHIM task categories addressed were the same as for the experts. A standard protocol for training, practice and home assessments was followed with each participant to enable standardized data collection across these idiosyncratic, realistic home spaces. Slides were presented, explaining the participants' task and experiences in the virtual home assessment. A research assistant served as a guide for each participant. The guide remained with each person throughout the home assessment and documented the tags created as well as any utterances made when the tags were produced (e.g. "I always put my glucometer here so I remember to use it as soon as I wake up"). A technical guide explained the VR CAVE and the use of the wand, and conducted a practice session until the participant indicated they were ready to complete the assessment.

A debriefing session was conducted after each house was viewed. A retrospective verbal protocol was designed to confirm the lay participant's tags and document the stated reason for the creation of the tags. Debriefing was conducted by doctorally prepared research team members with considerable experience in interviewing participants. The participant and debriefer viewed, on a 4K resolution, 28-inch monitor, a playback from the perspective of the participant of their exploration in each house. During this session, all tags were reviewed and confirmed and any documented reasons for tagging a feature were explored. Missing features and erroneous tags were explored and corrected. The feature, room and notes were docu-

Figure 2: CAVE display of kitchen environment with selectable point objects.

mented on a pdf fillable form initiated by the guide and finalized by the debriefer. The debriefer-captured features and notes were considered the "gold standard" and were used thereafter for analysis purposes. Overall, 54 unique features were tagged, resulting in a total of 73 features in these two phases of the study.

2.4 VR Home Context Refinement

Utilizing the list of tagged features, it became possible to analyze data further. The goal of the next phase was to further refine our list of objects according to their perceived usefulness for PHIM. Therefore, it was helpful to add functionality to the visualization application that enabled participants to virtually choose an entire object – as opposed to simply highlighting points. To enable users to select entire objects within the point cloud model, individual points comprising the objects were segmented via bounding boxes. To create the boxes, student project assistants used 3D software, bundled with the LiDAR scanner, that provides user interface features for analyzing point cloud data. Once a box was created, a standard label for the household object was attached to the virtual data. The research team developed a taxonomy of features and used this taxonomy to apply strict naming conventions – for example, a kitchen cabinet would have a box label of K_cabinet2. Boxes were exported from SCENE and loaded into the visualization application. In the CAVE, red outlines of the boxes appeared, indicating to the user that the corresponding object was selectable. This form of data representation, 3D boxes representing "point objects", together with providing the user an ability to select these objects in the CAVE, served as the data collection mechanism for this phase. An example of the 3D box outlines of the selectable objects within the CAVE is shown in Figure 2.

Sixty laypeople who reported being told they have diabetes participated in this fourth phase of the project. As in the previous phase, a scripted training session was conducted and a standard protocol for the home assessments was utilized. Instead of exploring complete homes, lay participants explored five rooms from different houses focusing on the same three prior standard PHIM tasks (medication management, self-monitoring and general information management) in successive VR home assessment sessions. The virtual renderings represented selected rooms from ten homes representing each of the four principal home types (detached, semi-detached, multi-unit, and mobile). The wand was used to select a maximum of two boxes (features) within each room. This made it possible to constrain participant choices to the particular PHIM tasks on which they were focused. For example, participants in the virtual kitchen could be asked: "Which object would be most useful? If there's another one, choose that." And reminded: "You don't have to choose any objects!" As the participants selected something in the CAVE, a change in color occurred and the box filled in, giving the participant a visual cue that the feature had been selected. The resulting data was written out to a csv file.

To analyze data from phase four and make it easier to visualize and discuss, an analysis tool (developed with Qt) was created to load multiple csv files and summarize participants' selections across objects and across rooms. This enabled team members to rapidly view participants' selections while collapsing data features such as rooms, houses, participants, or PHIM tasks. To enable a more human readable analysis, the tool generates a heat-map with colors that can be assigned back to objects in the CAVE, enabling a visual representation for analysis of location and proximity of features and objects to each other. This was necessary because in one room– for example, the kitchen– several different features with the same name – for example, the cabinet – could be found in specific locations; however, the labeling scheme could not represent a particular cabinet in a particular kitchen. Associating the selection frequency data with a visual representation of the object allowed for further analysis and consolidation, as well as providing interpretive freedom.

Overall, this phase enabled the team to refine the list of features already determined to be useful for PHIM by observing participants' sensitivity to them in different household settings. This refined list served as the basis for the development of the Assessment of the Context of the Home Environment (ACHE).

2.5 Validation with Real World

The ACHE is a survey developed by the research team used to document a set of household features in real world homes across a larger sample and geographic range in the final phase of the project. The ACHE's aim is to determine the presence and location (room) of the features that participants identified as most useful for PHIM, in the context of a public health-oriented community-based study. To understand how representative the original twenty homes were, a third party was recruited to help administer the ACHE in the greater project area. In this final phase, field staff completed the ACHE in more than 245 real-world homes. The field staff were recruited from a statewide public health survey designed to improve health in the state. The group who administered the surveys conducts annual health surveys with longitudinal follow-up and enables community-specific ancillary studies (of which this project is an example). The ACHE documents the presence and location of the key useful features in a home, as generated from the results of phases two–four, in a larger sample. This final data will be used to validate the results of the study against a larger, real world sample. Final analysis of the ACHE findings is still in process.

3 Discussion and Future Work

The research team has demonstrated the ability to capture, process and display point cloud data in the form of models of home environments. The team has exposed more than 100 community-dwelling, chronically ill individuals to a VR CAVE and found that they are able to navigate through the home models and coherently select objects and spaces in which they would perform specified health care tasks. The participants had remarkably few reactions to the virtual experience that would be suggestive of simulator sickness (score of 0-1 or none – minimal on 4 items of the SSQ). In addition, many participants stated that the experience was interesting and led them to greater insights into their self-care and information management practices.

Some members of the research team participated in a subsequent project aimed at testing the feasibility of displaying such a virtual home model via a link in the electronic health record and evaluating the acceptability of this display to health care providers. A single focus group revealed that clinicians were not only accepting of the technology, but enthusiastic about its potential for improving care planning and clinical decision making. The following clinician statement serves as an example: ... you know, many times people are sent home with a walker that never makes it in the house because pathways are too narrow ... this would be nice to know 'on the front end'.

Based on these focus group findings as well as clinicians' responses to research team presentations, we conclude that another area of healthcare that would benefit from using virtual home models like those developed in this project is transitional care or discharge planning, for example, after surgical joint repair or replacement. By combining LiDAR and VR technologies, a suite of virtual reality (VR) simulations and discharge planning activities designed to improve the safety and success of the transition-to-home process following hospitalization could be developed and evaluated. Growing evidence indicates that patients in transition from institutional care settings to home are often unprepared for the self-management role they must assume when they return home [16]. Key among the challenges to transition is the lack of representation and consideration of the context of the home environment in discharge planning. Co-occurring challenges include uncertainty about self management due to conflicting or unclear discharge instructions; capabilities and context that are not represented in discharge planning, and unresolved questions about managing anticipated or unanticipated problems [11]. The patient's experience of returning home may be complicated further by anxieties, confusion, and distorted sensations. Transitional plans that are comprehensive and support self-management in the home context can promote safe transition to home and potentially reduce readmissions. Creating the simulated experience of home environments poses new possibilities for the purposes of discharge planning and tele-rehabilitation. However, creating this simulated experience requires both the capture and display of actual physical environments.

Engaging patients in self-management and equipping them with the capacity to anticipate, plan and implement safe home care practices, and resolve problems may be improved if the discharge planning experience occurred in the familiar environment of patients' homes [20,29]. In-home teaching holds great promise for improving the transition experience; however few patients actually have the opportunity for a home visit by a health professional upon discharge. In addition, newly discharged patients and family are dealing with uncertainty as well as the stresses of transition. The research team posits that immersive VR environments provide an ideal setting for highly-tailored anticipatory guidance including simulations that prepare patients to work through realistic post-discharge challenges, plan responses to them and rehearse self-care activities in a virtual replica of their own home settings. When those immersive settings are exact visual replicas of the environment to which the patient will be discharged, one could expect that the visual cues will provoke a more comprehensive identification of safety challenges and strategies to improve self-care at the transition. Leveraging LiDAR scans of key areas of the home, and displaying the scans within a VR CAVE or HMD, would enable:

1. Pre-operative multi-disciplinary home assessment and anticipatory discharge planning with the patient

2. Learning and rehearsal of key health behaviors related to mobility, strength-building and self-care activities in a familiar environment

3. Requisite modification of the home environment to accommodate any equipment.

Furthermore, inclusion of informal caregivers and multiple disciplines is facilitated by the use of such a simulated environment.

4 Conclusion

The presented work demonstrates the use of VR for the improved understanding of health in the home. By simulating real environments, studies can be performed in ways that would not previously be possible. While the presented approach has already shown positive results, the true potential of using VR for the study of how the home environments shapes health has yet to be fully realized. Future potential areas of focus for using VR to study health in the home include the development of methods to improve transitional care and improved design of devices and procedures designed for these environments.

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