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Envisioning the Future of Home Care: Applications of Immersive Virtual Reality

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Abstract

Accelerating the design of technologies to support health in the home requires 1) better understanding of how the household context shapes consumer health behaviors and (2) the opportunity to afford engineers, designers, and health professionals the chance to systematically study the home environment. We developed the Living Environments Laboratory (LEL) with a fully immersive, six-sided virtual reality CAVE to enable recreation of a broad range of household environments. We have successfully developed a virtual apartment, including a kitchen, living space, and bathroom. Over 2000 people have visited the LEL CAVE. Participants use an electronic wand to activate common household affordances such as opening a refrigerator door or lifting a cup. Challenges currently being explored include creating natural gesture to interface with virtual objects, developing robust, simple procedures to capture actual living environments and rendering them in a 3D visualization, and devising systematic stable terminologies to characterize home environments.

Keywords:

Home care, self care, user-computer interface,

Introduction

As the locus of health care shifts from institutions to homes and communities, there is an urgent need to develop computer and biotechnology-based tools that can be safely and effectively used outside the hospital to improve health and quality of life. Thus, it is essential to accelerate the development-to-deployment process for personal care diagnostic and therapeutic technologies, supporting individuals and their families in the detection, recognition, and management of human health problems. We assert that the model of technology development must shift from a focus on activities in isolated, discipline-specific laboratories towards evaluation of the impact on the nature, availability of resources, facilitators, and barriers on personal health management engendered by non-institutional contexts, specifically households, where these health technologies will be used. We propose to use immersive virtual reality experiences, implemented in a six-sided Cave Automatic Virtual Environment (CAVE), to recreate a broad range of household environments, examine how space and task interact to shape the manner in which daily health activities in the home is performed, and glean insights for designers of health care technologies intended for home use.

This paper documents the systems in the Living Environments Laboratory and the research possibilities of merging virtual reality with the study of and improvements to home care tasks and home care information technologies.

Lay people can and do create effective ways to manage health information in the home, and find ways to make interesting modifications to their homes to accommodate personal care technologies [1]. Figure 1 depicts the retro-fitting of paper resources into the home; Figure 2 shows the awkward placement of a computer used to manage a person's health information in their living room. Far too little attention is paid to understanding the context wherein these devices are intended to be used and the motivation, skill, and physical abilities of the individuals who need to use them. What is needed is a systematic approach to the design, manufacture, and deployment of personal care technologies that improves their usefulness and value, and increase the likelihood that they can be as effectively used in the home as in the institution.


Figure 1 - Health information


Figure 2 - Crowded living room

In previous work by our group in the Health@Home [1] project, we visited almost 50 households and had residents show us where in the house they stored health data and conducted health care tasks. We obtained valuable insights about the physical, social, and technical environments of the home, and how health information is managed and by whom. We learned that there is no "typical" environment, since environments are ever changing in terms of physical, social, and environmental factors. We need to build technology not just for one environment, but also for many fluid ones. Our later work in Project HealthDesign [2] focused on the design of computer and information technologies to support health at home. Here we learned that the nature of health information managed by people at home far exceeds the standard clinical parameters (e.g. weight, blood glucose level) that clinicians anticipated being managed. These "observations of daily living" include such things as the tenor of conversation at the dinner table, or the number of unsuccessful attempts to perform a personal care task. Information about these observations could be obtained through active or passive sensors and could provide valuable insights into aspects of health, such as eating patterns or cognitive decline. For instance, through a web of sensors embedded in the clothing of the person and the walls of the house, we might detect early signs of deviation from routine that could signal a change in cognitive processes. These insights could inform the design of home care technologies.

Virtual reality (VR) presents individuals with visual stimuli that affords an experience of being immersed in a place remote from where one actually is [3]. Accompanied on occasion by auditory and tactile stimuli to create a sense of presence [4], VR has health applications for mitigating psychological problems such as phobias and post-traumatic stress syndrome [5]. VR also has commercial application in manufacturing and design [6], and in the entertainment industry.

VR offers 3D, full-color immersion into spaces that permit the user to navigate by walking or through use of a joystick. Objects can be manipulated (lifted, turned) provided the implementation that includes such physical properties. VR has two primary implementations: through a head-mounted device (HMD) and through immersive VR such as a CAVE[7]. HMDs use a helmet-type device that uses a video signal to display coordinated video on two small over-eye screens; they offer the advantage rich depth perception, but do not permit a user to engage in the scene with other participants or to see their own bodies. Immersive VR, implemented in room-size space, uses active or passive stereo glasses to enable users to see images as well as other participants in the scene. For the purposes of home care experimentation, visualization of others in the scene and ones' own bodies is essential, thus requiring a CAVE.

Traditional design processes begin with deriving product requirements from intended users, formalizing those requirements through functional specifications, constructing prototypes, testing those prototypes in simulated or actual use environments, making modifications, then moving the process into mass production. The engineering design process is well specified and supports both a user-focus approach [8] as well as a models-specification approach [9]. It is, however, largely decontextualized, focusing more on the work and the task than on the location where the work occurs. Engineering approaches capitalize on assumptions about the nature of the environment where the anticipated solution is intended to be used. Personal care technologies--tools for healthy living-- are subject to special constraints, high levels of variability in user skills, unstable physical environments (such as the high humidity of bathrooms), interaction with other electronic or physical devices in the home, and the lack of consistent electrical service and network persistence. Designers may be unaware of the parameters they are designing for and may take certain parameters for granted – for example, the height and depth of a kitchen counter-top, vs. that of a dining room table, or a coffee table.

Strategies from consumer electronics afford some insight into alternative design methods [10]. However, while these approaches better consider some of the physical aspects of the home, they rest on a voluntary user whose choice to employ a device is motivated by social or entertainment motives, rather than by health care needs. People trying to manage health problems may lack the motivation or knowledge to effectively use a device with the care and precision needed to ensure its proper function, and may not have access to the physical space needed to effectively use and store a device [11].

The LEL includes both real and simulated environments that, to varying degrees, replicate the home environments where personal care technologies will be used. The virtual home environments created in the CAVE stimulates the creativity of designers and better informs them of the contextual and human characteristics that must be addressed for successful design. These environments will allow us to introduce stressors such as limited physical space or low lighting, earlier in the design process, allowing designers to create new products situated in the environments where they are likely to be used. By judiciously employing simulated and instrumented environments we will not only provide test beds for rapid cycle development processes, but we will also be able to introduce stressors to determine product viability earlier in the design process. With design-for-use and design-for-manufacturing philosophies applied simultaneously to development, we anticipate accelerating not only the design process, but also the production process.

Thus, the LEL provides a laboratory to discover what aspects of the environment provide cues to health states, how information and computing technologies can acquire this data and present it back to the individual in meaningful ways. The analytics needed to learn what data is important, how much of it is necessary for knowledge development and how to manage that data can be acquired.

Materials and Methods

Laboratory

We designed a virtual-reality CAVE (depicted Figures 3 and 4) in which a system of coordinated projectors creates 3D, full-color displays.


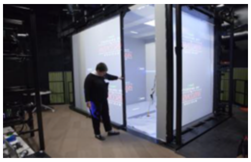

Figure 3 and 4- The CAVE in the LEL

The CAVE is located in the lower level of the Wisconsin Institutes for Discovery, a state of the art building located on the University of Wisconsin–Madison campus. The LEL contains a six-sided double-HD 3-D interactive rear-projected CAVE (9'6" x 9'6" x 9'6"). The CAVE (C6) is constructed as a room with four walls, a ceiling, and a floor. It has four rear-projection canvas display walls, one rear- projection solid acrylic floor, and one rear-projected canvas ceiling.

Each surface is displayed via two Digital Projection Titan 1080p 3D projectors blended in the middle, combining for a total of 1920 x 1920 pixels and maximum brightness of 4,500 lumens. The C6 display system has a sliding door that can open and close, thus converting the system between having five or six active display walls. The system also has a 5.1 surround sound Yamaha Natural Sound RX-V367 audio system and ceiling microphones for two-way communication. The C6 uses an Intersense IS-900 VETracker Processor with wireless Microtrax Wands and head trackers. Ultrasonic tracking emitters embedded into the C6 corners provide full 6DOF tracking of the head and wand. The head-tracking units are placed on RealD CE4 and CE4S shutter goggles to provide stereoscopic 3D viewing within the C6. The C6 also runs the Mechdyne "ACE" Dual View software. Dual View allows two C6 users to independently navigate through and experience the same content or different content simultaneously. An IP-based camera is mounted in the rear of the C6 supports streaming video.

Computational Core

The LEL CAVE has a PC real-time graphics cluster driving the display system. The cluster machines were equipped with Quad-Core Intel Xeon Socket 1366 E5640, 4core/8thread, 2.66GHz, CPUs, with two NVIDIA Quadro FX 5000 graphics cards, an utilized the 64-bit Windows XP operating system.

The CAVE cluster consists of eight workstations: two application nodes and six rendering nodes with four video outputs each. Each rendering node provides visuals for 2 CAVE walls per user. Additional resources include a development lab that has a mini-cluster consisting of an application node and a rendering node with two video outputs to run the one surface. It has an additional rendering node to be used for ACE Dual View. The rendering graphics cards, projectors, IR emitters, and shutter-glasses are all synchronized for multi-channel 3-D stereoscopic operation.

Software Environment

The LEL utilizes Mechdyne's VirtualLab software to display immersive 3D experiences in the CAVE. We refer to the entire set of visual images, objects, and functions as "Scenarios". The LEL has a license for using Mechdyne's proprietary CAVELib API to aid in custom software creation. In addition, the LEL also uses an internally developed software utility that integrates proprietary and/or open source software for custom software for display in the immersive environment. The CAVE system software supports standard 3D models, generated from tools such as SketchUp, Blender, and many of the AutoDesk tools. Scenarios and developed content are stored locally on a shared Windows fileserver.

Our lab makes use of an internally developed digital curation system running on a secure web server for archiving and retrieval of data and protection of data rights. The curation system has an in-building only accessible web front end that allows for browsing and storage of data used within the LEL. At the request of the project researcher, their data may be entered into this curation system. The curation system contains a section for data rights so that all digital work is attributed to its source author.

Interface Strategies

Living Environments Laboratory also possesses additional hardware and input devices for experimentation and research purposes. The LEL has 3 Microsoft Kinect devices, a Vuzix Wrap 920 Video eyewear device, a Nintendo Wii-Fit balance board, and a variety of game controllers such as a Sony Playstation 3 gamepad and a Microsoft XBOX 360game controller. Recent developments focus on use of an EMG-based interface to control virtual objects in the CAVE.

Home Environment Scenarios

The first virtual home created in the LEL CAVE was designed as a proof of concept. We created a virtual space of an apartment with 4 contiguous rooms, encompassing what would be approximately 400 sq ft of a physical apartment. The virtual apartment we created arose as an amalgam of general home structures, and was not intended to represent any actual home.

We focused our visualization and functional development on the kitchen (Figure 5) and the bathroom, recognizing that these are the two most common spaces where health activities occur in the home. Other spaces in the virtual apartment include general household accoutrements but lack the specification and functional considerations of the kitchen or bathroom. Development was a joint effort between our team at the LEL and the software division of Mechdyne. The LEL team identified the physical considerations, including specifications of objects, such as their functions and physical properties. Depicted in the Figure below is the kitchen of the virtual apartment. Note that the man is holding a paper towel roll; the red line represents an electronic pointer emanating from the wand that controls the virtual objects. Other interactive aspects of the kitchen include the ability to make the refrigerator and cabinet doors open and close, sound effects such as that which would be heard when the faucet is turned on, and a virtual radio.

Figure 5 - Research staff member interacting with paper towels in The Virtual Kitchen in the LEL CAVE.

Results

Implementation of Home Environment Scenarios

We successfully created a virtual apartment in the LEL CAVE. The images of the apartment are visible to an individual wearing active stereo glasses, and are presented oriented to a single individual's perspective through coordination between the Intersense tracking system and a device worn on the user's glasses. Development of each room took approximately 90 days, from idea inception to specifying components and functions of virtual objects, to programming scenarios. Virtual objects retain their physical properties as anticipated. Aberrant behaviors (e.g., objects getting stuck inside solid walls) are minimal and arise from software conflicts.

In a series of public open houses intended to introduce the community to the reality of virtual reality, over 2,000 individuals have visited the virtual apartment and have demonstrated that participants naïve to virtual environments are able to manipulate objects and tolerate up to 20 minutes exposure to the CAVE. The system has required an anticipated amount of maintenance, including balancing the color scheme.

We have begun to observe several challenges in the existing CAVE structure. In open dialogue between visitors to our open houses and the LEL staff, we've learned that the wand presents challenges for lay users to interact with virtual objects. Part of the work of the LEL is investigating more natural interfaces (such as gestures) with virtual objects so that it is possible to bring more participants into the space. We have also learned that the original designs of household spaces are overly neat and do not reflect the typical clutter and mess found in many households. In response to this, we have additional household scenarios with added clutter and mess. Finally we lack efficient ways to describe and classify the microenvironments of households in a manner that will allow us to link context with health behaviors. The development of the in-house digital curation system has already enhanced our understanding of the terminology problems inherent in management of VR systems, and work is continuing in this area.

Discussion

Virtual reality CAVEs provide feasible ways to recreate household environments and may prove helpful and an inspiration for design of new technologies to support home care. The result of the original collaboration provided evidence that the immersive experience within a 6-sided virtual reality CAVE evoked a sufficiently strong sense of immersion that individuals believed and behaved as if they were in an actual household. However, some technical challenges remain to be resolved prior to engaging in full-scale experimentation of household settings and the subsequent use of these environments for design.

Our challenges in moving from prototypical households to realistic households will require improvement in the ability to capture realistic households with all the objects, furniture, and clutter. Molony and colleagues [12] documented the importance of understanding not only the space where individuals live, but the objects they find familiar and meaningful. Thus it is critically important that we devise new ways to capture existing households, replete with the knick-knacks and functional layouts of different homes.

Future Direction for the LEL

Figure 6 - Artist and her work in the CAVE

The WID exists as an interdisciplinary nexus on campus. As a lab in the WID, we support the Wisconsin Idea by embracing an interdisciplinary use of the lab. We have engaged with many campus researchers, scholars in the arts, and industrial partners in various projects within the CAVE environment and these partnerships have directed our team to explore a deeper understanding of working in virtual environments. Our work has ranged from 3D plans for new construction, to an art exhibit [13] (see Figure 6 above, courtesy of Lisa Frank, MFA); and visualizations ranging from cloud patterns to molecules. Each of these projects has within them, a mark of presence and immersion that combine to create an experience that impacts CAVE users. Curiosity about these experiences drives our research forward.

Acknowledgments

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