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HazARd Fall PreNoSys Augmented Reality-Based Tripping Hazard Notification System and Initial User Feedback Study

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ABSTRACT

Falls and falling remains a significant problem for people as they age. This work proposes a mobile augmented reality (AR) based system called "Fall Prevention via Notification System" (Fall PreNoSys) to detect potential tripping hazards around the wearer and provide notifications to help them avoid safety problems, along with two phases of user feedback to improve the system design. Blending mobile technologies and human computer interaction requires significant work on human interface components to become an effective, calm, and useful tool in daily life. A series of human subjects testing was undertaken to gather feedback about the design, utility, and concepts underlying the Fall PreNoSys interface design and general utility. Current AR research in gerontechnology or in-home assessments is a new field and Fall PreNoSys is a novel approach to the area of fall prevention. The study used walking tracks with objects representing common in-home tripping hazards, a combination of machine learning-based detection algorithms, and multiple styles of visual hazard notifications. Study data was collected through two phases of interviews, user feedback of their experiences with the technology, and measurements using the System Usability Study scale to help guide further development of Fall PreNoSys and similar systems in the future.

Keywords: Augmented reality, User interfaces, Mobile computing, Gerontechnology, Senior care, Healthcare

INTRODUCTION

According to the US Centers for Disease Control, around one in four of all US adults aged 65 and over fall each year as of the 2020 data and calculates a fall death rate of 78 per 100,000 older adults as of 2021 data ("Older Adult Falls Data | Fall Prevention | Injury Center | CDC," 2023). The cost of these falls accounts for 0.1% of all healthcare costs in the United States annually and up to 1.5% of healthcare costs in European countries. The number one reason older adults have increased care needs is due to falls and fall related injuries.

The home is the most common location for seniors experiencing falls. Around 55% of all fall related injuries occur in the home (Pynoos et al., 2010), and 35% to 40% of those falls are directly related to environmental factors. New approaches to preventing, detecting, and assisting in fall management are of utmost importance to the clinical community.

During prior work by Zulas and Crandall in gathering clinical needs for senior care focused smart home technologies, nurses often cited the need for help with several common topics related to falls, clutter hazards, and home safety features (Zulas et al., 2014; Zulas and Crandall, 2014). When it came to falls, nurses normally focused on two major targets: clutter on the floors and hoarding.

In similar research, family members of seniors spoke of dealing with tripping hazards, in-home walking safety, and needing to keep the home orderly (Zulas et al., 2012). This demonstrates a need for proactive detection of hazards and notification to alert older adults of these issues as they move about their homes.

This work proposes and implements a real time, notification-oriented system that provides the home assessment process and performs real time hazard notifications to help prevent falls through automatic means called the HazARd "Fall Prevention via Notification System" (Fall PreNoSys). The Fall PreNoSys is a suite of algorithms using in-home 3D models gathered through sensor systems to provide real time notifications of tripping hazards. The overall goal was to alert the wearer to a potential tripping hazard so they could more easily avoid it. While an initial prototype of Fall PreNoSys has been developed, this work reports on a series of user interface and feedback tests to refine and improve the tool.

RELATED WORKS

While the Occupational Safety and Health Administration (OSHA) regulations (United States Department of Labor, 2021) speak to tripping hazards as an issue in clearing walkways and workspaces, as well as defining the required sizes for safe walking areas, it does not clarify many details about what would be considered a tripping hazard in a living space. To help better quantify whether a living/workspace is reasonably safe, approaches such as modeling fall risk and generating heat maps of fall risks in clinical environments have been developed (Novin et al., 2021).

Virtual Reality (VR) and Augmented Reality (AR) are both being used in healthcare for a wide variety of purposes. An example of using VR in care for older adults is using the technology to help train people learning to navigate with electric wheelchairs (Naves et al., 2016). In a similar setup, but with an AR style platform, Gaukrodger and Lintott (Gaukrodger and Lintott, 2007) demonstrated several applications of AR as an assistive technology. Pillai et al. (Pillai et al., 2022) used the Microsoft HoloLens AR system to gamify upper limb injury rehabilitation, which allowed therapists to track the patient's therapy compliance and recovery trajectory. These clinical applications are similar to approaches used by Fall PreNoSys, just applied to different needs.

Fall PreNoSys is a state-of-the-art contribution that uses 3D models of the area around the user, object detection with classification, and providing real time notifications to help orient the user to possible hazards around them. This work reports on both the technology and how users perceive the system while being tested in a lab environment.

METHODS

Fall PreNoSys Technology Design

The Fall PreNoSys system uses a 3D mesh model of the physical objects nearby as gathered by a Microsoft HoloLens v2 worn by the user. This Augmented Reality device both senses the physical environment as well as provides a multi modal set of interfaces to interact with the wearer. The device then allows for 3D virtual objects to be placed in the 3D AR space. These objects are rendered in front of the user's vision using an augmented reality style interface.

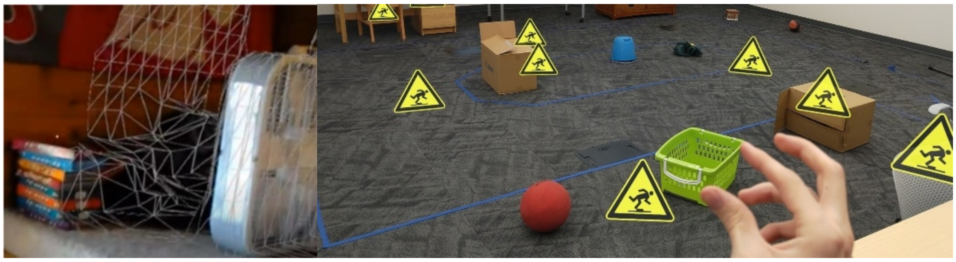

Figure 1: Visualizing the AR mesh and Fall PreNoSys basic hazard notifications. (a - left) HoloLens 3D mesh visualized. (b - right) Augmented reality interface screenshot as seen by the user during the experiment.

The HoloLens 3D mesh provides a spatial mapping of a home through a combination of infrared, vision, and depth mapping algorithms (Weinmann et al., 2021). This mesh is then interpreted for a combination of safe walking spaces and likely hazards. The current Fall PreNoSys system provides the real time alerts of possible hazards to the wearer via the AR interface screen.

The 3D mesh data is represented as points in three-dimensional space which are connected into triangles as a point cloud to provide an estimated surface area over the area around the user. A sample rendering of this mesh is shown in **Figure 1a**. Fall PreNoSys uses a combination of the HoloLens Scene Understanding toolkit and rules about physical size to decide if an object should be considered a tripping hazard and be given a notification for the user to see. The hazard classification algorithm determines that any object shorter than 0.9m (3ft) which is also resting on the floor to be included in the set of tripping hazards. The Fall PreNoSys interface used two kinds of 3D objects as visual notifications during the user testing. These were a traditional OSHA-style tripping symbol (United States Department of Labor, 2021) and a hovering arrow. A screen capture of these notifications is shown in **Figure 1b**.

The notifications drew upon several principles for user interface design for older adults (Boot et al., 2020). The colors were chosen for high contrast, movement of the notifications in the system was kept to a minimum, and the number of user interface elements was kept to under four to reduce working memory load ("Short-Term Memory & Working Memory | Definition, Duration & Capacity," 2019). Further, interface design research suggests "recognition rather than recall" (Experience, n.d.) to take advantage of already familiar interface elements rather than having to recall or learn the meanings of less familiar designs.

This is especially important when the familiar meaning matches the intended meaning in the user interface (Johnson, 1987).

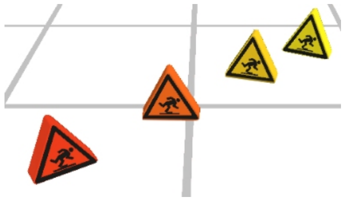

Figure 2: Fall PreNoSys Phase 2 notification colors at varying distances from wearer.

Phase 2 of the Fall PreNoSys interface design made these notifications reactive to the user's position and orientation to the possible tripping hazards. The visual notifications were changed so that the distance from the hazard would make them both change in color as well as to move when the wearer got very close to the object. These color variations are shown in **Figure 2**, and according to Johnson (Johnson, 2020), having high contrast, easily visible color changes increase attention and perception of alert levels, so the colors chosen for the symbol were the American National Standards Institute (ANSI) standard signage colors. The symbol also "bounced" up and down once when the user reached the close distance to help orient their attention to the possible hazard (Hillstrom and Yantis, 1994). The addition of varied colors and the bouncing motion were the key user interface differences being evaluated between the Phase 1 and Phase 2 feedback studies.

Iterative User Interface Design

An iterative design process was used during the development of the work presented in this paper. Currently, two design phases have been performed with additional design iterations planned for future work. Smaller iterative-style design phases were used for the user interface development and involved breaking down the process into focused cycles, each refining specific elements based on continuous (user-centered) feedback, adaptation, and improvement (Nielsen, 1993).

Participants

To gather desires, perspective, and feedback on the Fall PreNoSys user experience design, a total of fifteen participants were interviewed during the feedback study over the two design phases. Informed consent was obtained from each participant and the university institutional review board approved the study.

Phase 1: Ten of the participants were undergraduates between the ages of 18 and 23. One was a university staff member. Participants were 7 men and 4 women with an average age of 22 years of age and a range from 19 to 34.

Phase 2: All four of the Phase 2 participants were undergraduates between the ages of 19 and 20. Participants were 2 men and 2 women with an average age of 19.25 years of age.

Participant Recruitment: Participants recruited in these initial phases of the study were chosen to gain early prototype design feedback while the Fall PreNoSys interface is in the pilot stages of design. The participants recruited were selected to drive design choices before deployment with the eventual target audience of older adults.

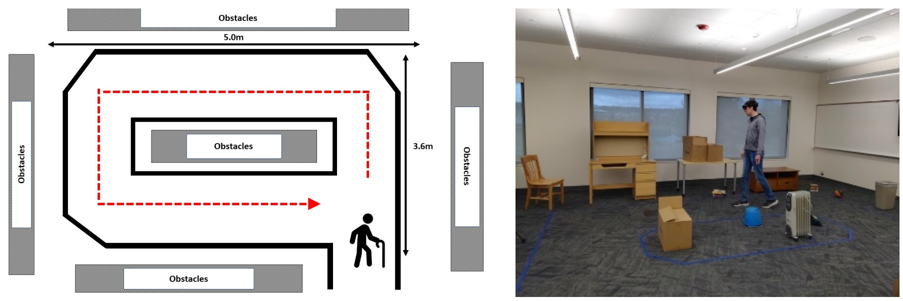

Figure 3: Fall PreNoSys Phase 1 feedback study. (a - left) HazARd Fall PreNoSys walking circuit diagram. (b - right) Participant walking the Phase 1 testing circuit.

Materials

Phase 1: Interviews took place in a research lab. The room was staged with a walking circuit for the participant to wear the headset as they walked past and around objects that could be classified as either tripping or non-tripping hazards. **Figure 3a** shows the general layout of the walking circuit. Overall, the circuit was 3.6m x 5m in size and outlined with blue painter's tape to show the participants where to walk while the notifications were shown over the objects in the areas marked "Obstacles." The participants did not have to walk through the obstacles for safety reasons.

Items placed around the walking circuit were selected as general in-home or everyday living items. These were a variety of colors, sizes, and shapes as shown in **Figure 3b**. The HoloLens v2 was able to detect and note most of the items for classification by the HazARd Identification Algorithm. Items smaller than 20cm wide are too small for the Fall PreNoSys algorithm to differentiate, mostly due to the resolution of the mesh provided by the Hololens (Weinmann et al., 2021). Roughly 15 notifications appeared with each walk of the circuit.

The participants were provided with a pre-walk and post-walk questionnaire. The pre-walk questionnaire included demographic and background information about the participants related to their experiences and perceptions of AR/VR technologies, falls and falling with older adults. The post-walk questionnaire included the System Usability Scale (SUS), open questions about their perceptions of the technology, and other places the technology could be deployed. The SUS is a 10-item questionnaire with a 5-point Likert-like scale that assesses the ease of use and understandability of a system (Brooke, 1996). Scores are modified for reversal questions and then totalled and multiplied by 2.5 to give a score out of 100.

Figure 4: Fall PreNoSys Phase 2 walking circuit.

Phase 2: Changes made for Phase 2 were to use the new user interface with the reactive and attention-getting notifications, as outlined in the Fall PreNoSys Technology Design section above. The participants were given the same set of instructions as in Phase 1. The Phase 2 walking circuit shown in **Figure 4** was designed to demonstrate the distance-based dynamic notifications, including the "bouncing" notification to move a notification into the AR device's field of view.

Procedures

The procedure remained the same for both phases of the design study. Prior to experimentation, participants were provided a description of the experiment, their role, and informed consent. Once informed consent was given, the experimenters started an audio recording and administered the pre-walk questionnaire.

After being shown how to use the headset and where to walk, once the participant completed the first circuit, the researchers changed to the HNI arrow style of notifications, and the participant was instructed to walk the other direction around the circuit. After both walking circuits were completed, the participant was given the post-walk questionnaire. To wrap up, any concluding thoughts were recorded, and the participant was released.

Analysis

As with the procedures, the same process was followed for analysis of both phases of the study. Recordings were transcribed into text and reviewed by multiple observers for inter-rater reliability. Observers placed topics into groups and sorted by frequency seen during the interviews. Topics that were more frequent and therefore emphasized by the participants were then included here as the main themes in this paper's results.

RESULTS

Overview: Both Phase 1 and Phase 2 of the Fall PreNoSys participant feedback studies were completed successfully. All data in written and recorded forms were available for processing by the reviewers.

Phase 1 Results: Interviews were completed successfully, and the system was generally well received. Participants stated that the system was "cool," "very interesting," and "I wish I could have this all the time."

Of this research project's participant sample, 9 of 11 had prior VR experience and 4 of 11 had AR experience. This is in line with the popularity of the two kinds of technologies. Mobile AR style systems have less market penetration and less use for entertainment and training, so fewer people have experienced them.

Among the group, 6 of 11 had provided at least some care for family members while 9 of 11 reported that at least one family member had recently had trouble with falls or falling. None of the group had experience as a formal caregiver in a clinic or other medical facility.

The results of the SUS varied greatly with a score as low as 40/100 and as high as 90/100, with an average score of 74.6. Higher scores did not necessarily correlate with greater prior experience with AR/VR technologies. Women rated the technology marginally better than men at 78.7 vs. 73.2.

Several themes began to emerge from the interviews that helped guide ideas about how the technology should move forward. Notably, the negatives centered around the intrusiveness of the notifications and the size of the headset for daily use. Other themes focused on possible situations and future development trajectories for the work.

Phase 2 Results: Like Phase 1 results, the system was generally well received with statements asserting that features of the system were "kind of cool" or "I really like it. It's really cool" and "definitely useful."

Of this research project's Phase 2 participant sample, 3 of 4 had prior VR experience and only 1 of 4 had AR experience while 3 of 4 had at least some informal care for family members. This remains in line with the popularity of the AR technologies and informal senior care experiences we saw with Phase 1.

The results of the SUS for this phase varied significantly less than in Phase 1 with a score as low as 75/100 and as high as 85/100, with an average score of 80. Higher scores did not necessarily correlate with greater prior experience with AR/VR technologies. In this Phase 2, we saw the opposite to Phase 1 when comparing the responses based on gender. Women rated the technology marginally worse than men at 76.25 vs. 83.75.

Overall Excitement

Among the participants' responses, all of them were positive in various ways about the technology. The most common statements were "cool" and "I'd like this in daily life." After experiencing the Fall PreNoSys applications, most participants were excited about the possibility posed by the AR-based technologies. They could see how it would provide extra information to someone navigating a home, or outside, especially an older adult who may not be as quick to notice objects.

Conveying How Much Risk Is in View

Several participants noted that all tripping hazards get the same treatment regarding how notifications are displayed, regardless of how the wearer perceived the relative risk of the object. The symbols used did not scale for some kind of risk measure, size of the object, or distance. It was noted that scaling the symbols by distance would help the user gauge the risk level themselves.

Type I Errors - False Positives

The current Fall PreNoSys algorithm generated false positives during the tests. Participants noted that some symbols ended up on the floor or desks. This led to discussions of what constitutes a tripping hazard for different people.

Type II Errors - False Negatives

Some objects that were clearly tripping hazards were not flagged as such. These were often smaller and darker shaded objects which the HoloLens v2 mesh was not detecting effectively. Participants often noted these limitations.

Notification Style

Participants received the different types of notifications in various ways. Most of them were most appreciative of the OSHA style tripping hazard symbol. This was a clearer notice of what kind of hazard was there as compared to the arrows.

Two participants noted that in the test environment there were a lot of objects that should be flagged with notifications. This led to a "sea of notification symbols," which is a common problem in busy information environments. Here, a cleaner home with less clutter would be visually emptier while a cluttered home would end up with many more notifications while the person navigates. Users who spoke about the quantity of notifications noted that they ended up being distracting.

Several participants spoke to the notifications being more consistent about their placement to the hazards. They wanted the visual notification to be placed so that they could always avoid the object in the same way instead of having to inspect the hazard and pick their own route. Similarly, participants also spoke about the notifications possibly encircling the hazardous area instead of hovering over the object. They wanted the notification to highlight where to not walk instead of just noting the object's existence.

Differences Between Phase 1 and Phase 2

The implementation of object detection and notification rules meant that participants in Phase 2 experienced notably fewer Type I and Type II errors. This led their comments to be more about the ideas behind the technology, how the notifications reacted, and their experiences with the AR system itself.

Participants also noted the color changes on the notifications often, implying that it was gathering their attention, though a couple noted a lack of color contrast. The authors feel that the standard ANSI attention colors are not rendered as effectively as necessary by the HoloLens AR screen, so more work is needed to ensure the varying notifications are more distinct in both color and style.

CONCLUSION

Healthy aging and supporting mobility impaired individuals shall continue to be a valuable field of research efforts. Building novel tools and approaches to identifying safety issues and hazardous situations should be a key contributor to helping people age in place, live safely at home, and to help caregivers be more effective. The HazARd project's Fall PreNoSys augmented reality-based approach to real time tripping hazard notification demonstrates a means of reducing falls in mobility impaired individuals. Because it is a mobile platform with a combination of world modeling, machine learning, and user interface design there are many questions to resolve to make it able to handle many real-world situations, how it might be integrated into daily life as a mobile ubiquitous computing system, and its effectiveness at truly reducing falls.

This work's evaluation of Fall PreNoSys centered around people's perceptions of the system, the concepts and ideas behind the tools, and features of the human computer interaction dynamic. The participants universally felt that this kind of technology could be helpful in numerous ways and that the improvements made from Phase 1 to Phase 2 of the project did indeed help the users orient to hazards near their walking route. The higher SUS scoring results in Phase 2 compared to Phase 1, though not a basis for any statistically significant claims due to current sample sizes, is an encouraging sign that the use of an iterative user-centered design process can help stimulate positive design changes. Their feedback suggests that improvements to the design of the visual notifications, location and quantify of the notifications, and how to handle out of view hazards would be key improvements to future implementations.

FUTURE WORK

Future work on augmented reality-based tripping hazard systems could include additional rating and heuristics of possible objects as hazards to improve the utility of notifications, the use of eye tracking so users can remove notifications once they have seen a given hazard, and to use more vision processing approaches to classify objects nearby to increase the richness of the hazard rating system. These improved object detection and classification algorithms should also contribute to projects that focus on clutter and walking space analysis.

These kinds of Fall PreNoSys systems should also be tested in larger scale real-world environments. The evaluation should include hazards seen in outdoor and non-in-home situations where a user is visiting other homes, offices, or other locations. Testing the hazard detection algorithms, and then evaluating the effectiveness of the notifications should be an ongoing effort to bring these mobile everyday supports to the wider world.

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