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Augmenting space: Enhancing health, safety, and well-being of older adults through hybrid spaces

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Abstract.
BACKGROUND: As the older adult population in the U.S. continues to grow, it has become a priority to ensure the health, safety, and well-being of these individuals while maintaining their dignity and autonomy.
OBJECTIVE: Memory loss and physical impairments have been identified as factors that restrict older adults from living independently. The objectives were (1) to develop a hybrid space within the participants' living environments using an Augmented Reality object location and information system based on visual and spatial organization and (2) to assess the users' perceptions of using such technology.
METHOD: Three older adults who had a physical impairment and also suffered mild memory loss participated in the study. These three individuals were provided with the mobile system, and their subjective responses were documented through interviews and a questionnaire.
RESULTS: The results of the study suggest that participants found the system very useful and easy to use.
CONCLUSIONS: The results of the study suggest that the older adults who took part in the study were very open to the idea of using such an AR object location and information system based on visual and spatial organization hosted on electronic mobile devices to enhance their living environments.

Keywords: Augmented reality, mobile systems, older adults, independent living

1. Background

Memory issues are considered to be one of the preliminary indications of cognitive degeneration. Diseases such as Alzheimer's and dementia affect the memory of the individual. It is estimated that 5.4 million Americans may have Alzheimer's disease [1]. In a survey conducted by the Centers for Disease Control and Prevention (CDC) on older adults above 60 years of age in 21 states, 12.7% of the respondents reported increased confusion or memory loss in the preceding 12 months [2]. In addition, the survey projected that as many as one in eight U.S. households may have an adult with worsening memory loss or confusion. In instances like this, worsening memory is an unavoidable process, and older adults occasionally forget where they leave objects they use regularly.

A number of studies have identified memory loss as a barrier to independent living [3,4]. In addition, physical disabilities often prevent older adults from living safely and independently in their homes and ultimately result in caregivers being needed for support. Therefore, assistive devices that may help physically disabled older adults with memory issues are needed to enable them to live in a dignified and independent manner.

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Autonomy is identified as one of the six dimensions of well-being [5]. Autonomy within the context of older adult living is defined as "individual control of decision making and other activities" (p. 669). Dignity in the context of older adult living denotes "individuals maintaining self-respect and being valued by others" [6]. Walsh and Kowanko [7] state that factors such as respect, privacy, control, choice, and humor are linked to the concept of dignity. From this perspective, autonomy (or control) can be thought of as a facet of dignity. Importantly, this autonomy or sense of control over one's environment has been seen to influence motivation and memory performance [8].

Therefore, this study, focused on adults over 65 years of age who suffer from a combination of mild memory loss and physical disabilities. The objectives were (1) to develop a hybrid space within the living environment using an Augmented Reality (AR) object location and information system based on visual and spatial organization and (2) to assess the user's perception of using the AR technology. The ultimate goal of this study was to provide a mechanism for older adults to live an independent and dignified life.

The current study was unique in two ways. Firstly, while previous research had used Spatial Augmented Reality and Marker Based Augmented Reality, the current system proposed to use Simultaneous Localization and Mapping (SLAM) object tracking for Augmented Reality. While Spatial Augmented Reality is defined as augmenting the user's physical space by directly integrating images in the user's environment through projection systems [9], Marker Based AR uses markers to superimpose virtual objects on the physical space [10]. Object tracking for augmented reality in our current project used a Simultaneous Localization and Mapping (SLAM) system, in which objects were identified with respect to their surroundings.

The innovative changes in the current project enabled the system to identify important objects in the older adults' environments and to provide the older adult users with previously inputted information regarding these objects. The system employs SLAM based AR, which strives to assist older adults in living independently by overlaying information in their living environments, thus creating a hybrid space. This intervention allows for the creation of a digital overlay over the existing older adults' environments so that the environments do not have to be physically labeled by caregivers. Therefore, the current system provides a valuable aid to older adults, which is anticipated to allow for more dignity in their daily routines and to potentially increase independence in these older adults.

Secondly, the main focus of the current study was to understand how older adults perceive AR technology. While technologies such as AR are gaining popularity and expanding through mainstream media and media devices, it is questionable whether people are using them for their practical value and/or satisfaction. Olsson and Salo [11] suggested that the current use of such technologies is based solely on novelty and curiosity value. Gabbard and Swan [12] stated that recent research on AR has for the most part focused on the development of the technology and that whatever user evaluation has been done has focused on technical aspects rather than using a human-centered approach. Both system and user performance measurements are important aspects for AR since the technology coordinates between the physical environment and the computer generated overlaid environment [13]. In the current study, the Technology Acceptance Model (TAM) [14] was used to understand how older adults perceive this technology in terms of usefulness and ease of use. TAM suggests that two factors, Perceived Ease of Use (PEU) and Perceived Usefulness (PU), are significant determinants of attitudes toward Intention of technology Use (IU) of a technology-based system, and it is a widely cited method for analyzing user acceptance and the use of technology [15]. Moreover, TAM has previously been used to analyze PU and PEU in mobile systems [16], with the long-term goal being to develop effective strategies for the development of such systems through prototype testing. By obtaining information regarding perceived ease of use and perceived usefulness that is based on the TAM, the likeliness of older adults using these types of technology in the future can be predicted.

2. Augmented Reality (AR) in design

AR has been defined in many ways. One of the more accepted definitions of AR states that it is a variation of Virtual Reality (VR) [17]. While VR immerses the user in an artificially created digital environment that is disconnected from the surrounding physical environment, AR provides the user with information about the surrounding physical environment by overlaying the virtual over the physical. These virtual components can consist of information in the form of text, 2D graphics, or 3D graphics.

Currently, individuals of all ages interact with the environment through interfaces that are digital or physical. Digital interfaces can be seen in newer thermostats that have a touch screen interface; a physical interface is something as simple as a light switch. These interfaces play a major role in how we experience and interact with the environment [18]. New media interfaces offer many options such as interactivity, responsiveness, dynamicity, and intelligence. These interfaces allow users to experiment with space in cost effective ways with minimal impact to the physical structure of the space. Technologies such as AR have affected the way that we interact with space and other people [19]. AR has been used as a means of making people interact with space, and thereby affects the way people live. This phenomenon has been seen in AR games [20], tools for designing spaces [21], and navigational guides [22]. In addition to developments in interface technology, mobile electronic device usage has increased within the last couple of years and has become a way of interacting with the environment – ranging from social media interaction to being a part of the Internet of Things (IoT). The connection between space, media, and the internet through electronic mobile devices has led to the development of hybrid spaces.

Hybrid space is a term used to define a space where the digital space seamlessly interacts with the physical space [23]. Lee [24] stated that one of the outstanding effects of mobile devices is that they tend to blur the boundary between binary realms such as public and private spaces. He stated that due to the developments in mobile technology, it is not their physical presence that decides whether people occupy public space or private space, it is their choice. The way people experience space is subjective, and places don't necessarily mean the same to everyone [25]. Personalizing public space can be achieved through layering of personal data over physical space. This phenomenon has been seen in popular augmented reality games such as Pokemon Go [26]. While physical space is the environment that surrounds us, digital space is defined as digital information that is overlaid on the physical environment. Merging of physical and digital space is identified as hybrid space [27]. Similar to the physical environment having fluctuating parameters for becoming a successful place, the addition of the digital overlay brings about new parameters in creating the experience of place. These new ways of experiencing space and place may also help older adults in place making, especially if they are surrounded by a new environment. Understanding the affordance of these technologically enriched spaces may help designers manipulate and better design these hybrid spaces.

Apart from the more commonly investigated aspect of AR providing opportunities to experience space, prior research has proposed using AR applications to assist patients with memory loss [28]. While some studies have examined using AR for rehabilitating stroke patients with memory issues [29–31], using the technology to focus on independent living for older adults has not been published previously. The system described in this study focused on older adults with mild memory issues and investigated the use of a mobile Augmented Reality system that uses object tracking to provide information and location of objects in the environment.

The use of AR to help older adults with mild memory issues stems from the fact that AR interfaces require low levels of cognitive load [32]. Cognitive load theory was first defined by Sweller [33]. He suggested that if an interface is complicated and difficult to navigate, a higher workload will be imposed on the user. Cognitive load can be defined as the total amount of mental activity on working memory at an instance in time [34]. Wilson [35] stated that cognitive processes are deeply rooted in the body's interaction with the world and that people off-load cognitive work onto the environment to help them work efficiently. Researchers have explored how cognitive load affects the decision making process [36], as well as how cognitive load affects performance [37,38]. Many researchers have suggested that cognitive load can be reduced through interfaces such as Augmented Reality [39–41]. Studies have shown that aging reduces the working memory capacity [42,43]. Furthermore, studies have also shown that older adults use mental representations to reduce cognitive load [44] so that they can manage with the working memory capacity they have. Using interfaces such as AR that impose lower cognitive loads may help older adults manage their working memory.

Several projects have developed AR mobile systems for navigation [45,46], visual tagging systems [47], and even edutainment systems [48]. Previous studies have also explored the idea of using AR to "tag" spaces with audio and text to assist individuals with conditions such as Alzheimer's [49,50]. As the use of mobile devices by older adults increases, a similar increase in using AR among older adults has also been observed [51].

Research on AR system utilization, by older adults, has been previously carried out regarding; 1.) AR based navigation systems [52–55], 2.) training for older adults using AR systems [56–58], and, 3.) entertainment [59,60]. AR based information systems, similar to those utilized in the current study, have also been developed [28,49,61]. Previous studies have explored the use of mobile systems by patients suffering from memory loss [62,63], and other studies have used marker-based tracking [28] and radio-frequency identification (RFID) tracking [64–66] to identify and provide information regarding objects and the environment.

3. Methods

A convenient sample of three participants ($n = 3$) were recruited for the study, which took place over a period of six months. Two participants were female, and one was male. One participant was a wheelchair user, while the other two could walk unaided but had issues moving their arms. Participant recruitment was conducted through emails and notifications to different institutions and organizations in a southern midwestern state in the U.S. after the Institutional Review Board had approved the project. For each institution and organization, a point of contact was identified. The inclusion criteria consisted of older adults above the age of 65 who suffered from mild memory loss and some form of physical disability. The selection criteria were verified through the participants' physicians. After providing informed consent, each participant was provided with a monetary incentive for taking part in the study. Participants were informed that they could stop at any time and did not have to answer all questions. No personal information was collected, and only researchers had access to the information collected.

The data collection involved three phases. In the first phase, the researchers visited the participants where they lived and interviewed them regarding their needs, including the need for a mobile system such as the one proposed. During this phase the participants mentioned things that they had trouble finding in their homes. The participants also specified places in their own home that they had more difficulties in finding objects. Due to time constraints the researchers focused on these areas of the house and specific objects the participants mentioned rather than scanning the entire house. The second and third phase occurred approximately one week after for two of the participants and three weeks after for the other participant due to that participant's availability. The second phase consisted of the participants using the mobile application and the third phase consisted of the participant answering a questionnaire right after the second phase.

3.1. Phase one: Interview

In the first phase the following questions were used as conversation instigators:

1. How easy is it for you to find something in your room?
2. Do you feel that you forget where you leave something?
3. Do you remember where you left your medication today?
4. Are you able to locate your clothes easily in the morning?
5. How well do you think you can move around in your room without someone else's help?

These questions were developed to understand cognitive as well as physical impairments of the participants. In developing these questions, established questionnaires on assessing memory impairments were used [67].

In the same first phase of the investigation, the researchers 3D scanned selected spaces in participants' home environments (i.e., bedrooms or living areas) using the Metaio Tool Box© application with an iPad. Other methods, such as mobile 3D scanning (using accessories such as the Structure sensor), were investigated as alternate methods, but given the accuracy and efficiency of the Metaio Tool Box, it was used. This selected method could be easily replicated by future users without any added cost. One of our goals was to choose an Augmented Reality workflow that would not require programming knowledge after the application was developed.

Researchers then created a 3D data point cloud for each of the home environments. A 3D data point cloud is a set of data points usually defined by the X, Y, and Z coordinates, which can be used to form points on the surface of objects or within spaces. The 3D data point cloud was extracted from the Metaio Tool Box scan that was conducted and was then used to facilitate overlaying information on elements of the home environments, such as a kitchen as shown in Fig. 1. These AR information labels were visible only to the users (participants and anyone using the mobile system), not to visitors, which created a personalized experience that enhanced the sense of dignity for these older adults. These AR labels were considered as an alternative to placing physical labels within the physical home environment (i.e., attaching sticky notes to the faces of cabinets and drawers). The SLAM object tracking system that was used, allowed the overlaying of objects on the physical space without the need for having special

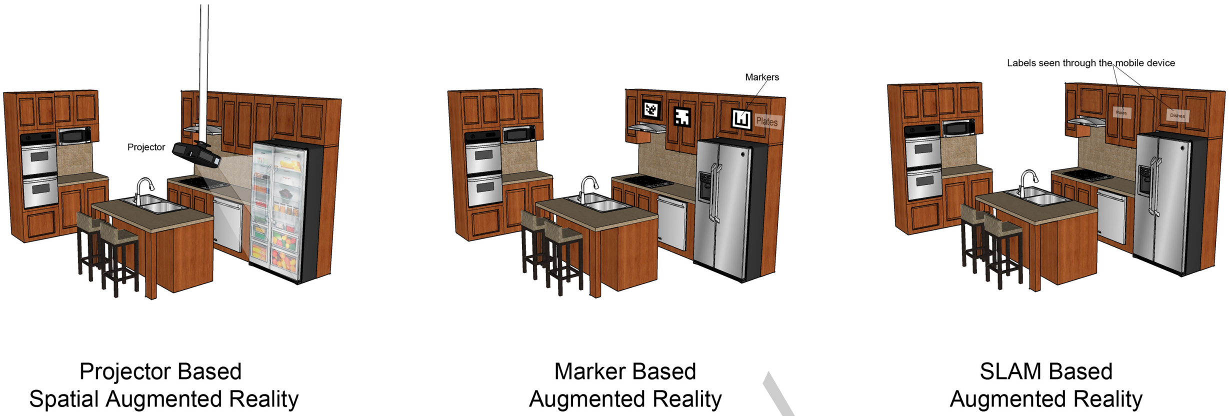

Fig. 1. Spatial Augmented Reality, Marker Based Augmented Reality, and SLAM Based Augmented Reality.

Fig. 2. Point cloud of the kitchen area.

markers or any other type of indicator since the system tracked elements in the environment.

In developing the system, the researchers imported the 3D data point cloud (Fig. 2) into the Metaio Creator© application and added labeling information. The point cloud acts as a 3D mesh on which the information (labels) can be attached. Given the 3D nature of the point cloud, irrelevant of the position of the user, the labels remain in the same place in space. This can be likened to attaching invisible post-it notes on the environment that are only visible through the AR system. The data cloud with labeled information was then hosted on the Metaio© servers and was made accessible through a mobile system developed using Eclipse© Java development tools.

Figure 3 shows how the system was designed to provide one-click/tap access, the simplest user interface. The user clicks on the system icon on the mobile device and this opens the interface. The system interface is a viewfinder that uses a mobile device's camera. No additional buttons or instructions are required.

Figure 4 shows a participant using the system in his/her kitchen. The system utilizes object tracking for AR, which enables it to identify objects in an environment, such as a kitchen, and to provide information on items to use, such as china, recipes, etc., through AR overlays on the environment.

3.2. *Phase two: Mobile system testing*

In the second phase of the investigation, participants were asked to use the developed system for 5–7 minutes. The participants used the mobile device that was provided and accessed the application that had already been installed. By standing about 15 feet in front of the area that was scanned, the participants looked through the application to view the area (see Fig. 5). During these sessions, the participants were asked to identify what they saw through the viewfinder of the application. All participants identified the labels that were overlaid on the physical objects (as shown in Fig. 6).

The objects were initially tagged by the researcher. However, the application was hosted online on a cloud-based platform, so these information layers could be updated easily using a computer with the appropriate programs. In this study, however, the intention was to test the user interface of the system. A long-term goal of this study remains to allow caregivers to update object locations.

After participants had used the system, the perceived usability of the system was analyzed using qualitative data derived through structured interviews focusing on Perceived Usefulness (PU) and Perceived Ease of Use (PEU).

3.3. *Phase three: Questionnaire and second interview*

At the end of the second phase, the participants were asked to complete a questionnaire based on the Tech-

(a) (b) (c)

Fig. 3. Interface of the system and the steps in operating: (a) system icon, (b) system splash screen, and (c) system interface.

Fig. 4. Mobile system testing by a participant in his/her kitchen with an iPad.

nology Acceptance Model (TAM). The questionnaire consisted of 9 questions that focused on Perceived Usefulness (PU) and Perceived Ease of Use (PEU) of the system that was used in the current project. In this phase they were also interviewed using questions based on the TAM. These were more open ended questions aimed at understanding the intention of using technology in the future.

4. Findings and discussion

An interview was conducted with participants in the first and third phases of the investigation. The interview in the first phase was conducted to understand the needs of the participants before developing the proposed system and allowing the participants use it, and the second interview was conducted during the third phase after the participants had used the system and was designed to understand how the participants perceived the technology. A questionnaire was also completed by each participant after he/she had used the system. Because there were only three participants, the information from the interviews was summarized and is provided in the following section.

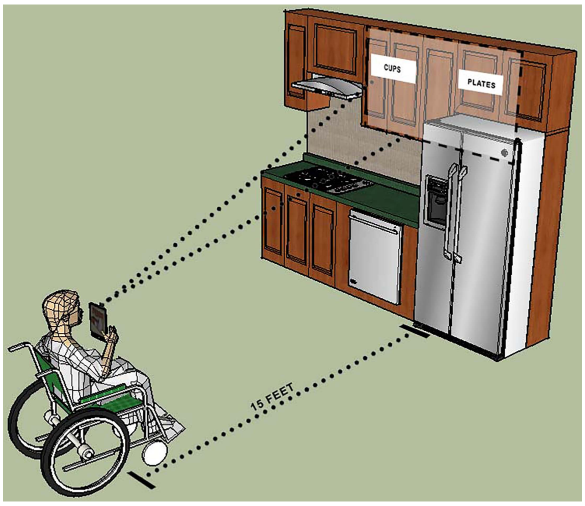

Fig. 5. An individual using the AR system through a mobile device.

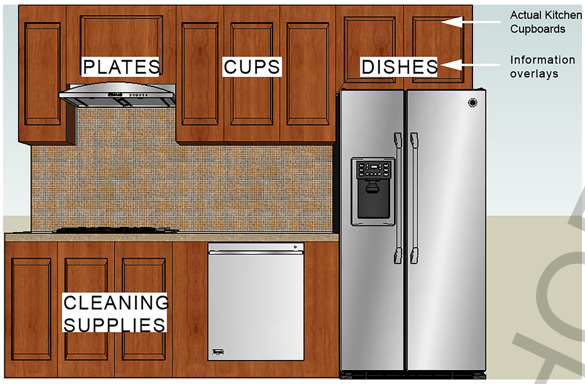

Fig. 6. Kitchen cupboards overlaid with the augmented reality information layer.

From the first interview, all three participants reported that objects that they use daily are easier to find, while things that they do not use often, such as a pair of binoculars, are harder to find. One participant had a caregiver who kept track of objects and would help find the objects that were needed. Two of the participants had already adopted organization mechanisms to help them locate things. The mechanisms involved keeping like objects grouped together, such as keeping all phone directories in a designated drawer. Two participants mentioned that even though they had a system to keep things organized, sometimes it became hard to remember where everything was. Also, using labels on closets and drawers to make it easy to remember where things were made the space distracting and unattractive. Participants also kept their medications well organized. Two of the individuals kept notes using notepads "to keep track of things" that they might otherwise forget. While two of the participants had no issue in moving around their homes unassisted, one participant did not move or work without assistance, even though the house was specifically designed to live unassisted.

The discussion from the first phase provided the following results:

1. The participants ($n = 3$) had adopted organizational systems that they used to remember where things were kept in their homes. One participant mentioned he/she used labels on drawers to indicate what each drawer contained, but gave up on it because it was distracting and made his/her house look "*ugly*."
2. The organizational systems chosen were difficult to use and expended valuable cognitive load, which individuals could have used for other purposes. The systems also affected the way participants lived and were perceived, such as being labeled by others.
3. Even though the participants' environments were specifically designed for older adults to live in independently, participants reported that they were unable to live independently.

In the second phase, the mobile system was provided to the participants to be tested in their own living quarters. Each of the three participants used the mobile system for approximated 5–7 minutes. After using the system, in the third phase, each participant was provided with the questions listed in Table 1 on Perceived Usefulness, Perceived Ease of Use of the mobile system. The questions were presented in an interview format as well as through a questionnaire based on the TAM to gauge their perception of using the mobile system (see Table 1).

Perceived usefulness: with regard to the usefulness of the system, all three participants mentioned that a system like this would be very helpful in the following instances:

– In organizing items inside closets and to know where items are without opening drawers. This would eliminate the need of checking shelves that are more difficult to reach. This would be helpful, especially for individuals who are in wheelchairs.
– In the kitchen where objects could be labeled with expiry dates so that older adults would know when to throw items out. Also, a system like this could be helpful to let older adults know when certain food items are running low so that they are reminded to purchase them.

Table 1
Technology Acceptance Model (TAM) questions

1. I believe using a mobile application such as this will improve my day to day activities.
2. I believe using a mobile application such as this will enhance my effectiveness.
3. I believe using a mobile application such as this will increase my productivity.
4. My interaction with the mobile application was clear and understandable.
5. I found it was easy to get the mobile application to do what I want it to do.
6. I found the mobile application was easy to use.
7. Using technology such as this mobile application makes work more interesting.
8. Using technology such as this mobile application is fun.
9. I look forward to using technology such as this mobile application in my day to day activities.

- In enhancing the security of older adults. By knowing where things are located, it would eliminate unnecessary movement (by wheelchair or crutches), creating a safer environment.

Perceived ease of use: with regard to the ease of use of the system, the participants mentioned that the system was easy to use for the following reasons:

- "There were no buttons to click"
- "There were no menus, and it did not need any instructions"
- "It was very similar to the experience of using a regular camera"
- All participants owned an electronic mobile device, such as a smart phone or a tablet. Because of this, using such a system did not require additional effort. One participant mentioned that she used her tablet mainly to play games and check email, and having such a system to help her with her daily routine never occurred to her.

Attitude toward technology use: with regard to the intention of using the system in the future, the participants mentioned that if such a system were available they would definitely use it because it made interacting with the environment interesting. One participant also mentioned that using such a system would allow him/her to not rely on others for help for everything. All three participants mentioned that if this system was made available to them, they would definitely use it to help them with their daily activities. They also mentioned additional features, such as shopping lists, that should be included in the system. Apart from the living areas, participants suggested that a system such as this could also be helpful in bathrooms.

The follow-up questionnaire included similar questions on Perceived usefulness, Perceived ease of use, and Attitude toward technology use. On the questionnaire, the three participants were asked to rate the different items on a Likert scale that ranged from 1–7 (Strongly Disagree – Strongly Agree). All items were rated very high (7), which indicated that participants found the system very useful and easy to use.

5. Conclusions

This study focused on developing and testing a mobile system to help older adults (age over 65) who suffer from mild memory loss and physical disabilities. The objectives were (1) to develop a hybrid space within the participants' living environments using an Augmented Reality object location and information system based on visual and spatial organization and (2) to assess the users' perceptions of using such technology.

This study looked at some of the main concerns of older adults in living independently and with dignity. The system that was tested and developed focused on improving the health, safety, and well-being of these individuals through aspects such as improving autonomy and dignity by providing visual aids to locate important items such as medications, reading glasses, and books. While previous studies have looked at creating systems such as the one proposed, the current study took a human-centered approach using a small number of participants to understand various concerns in using technology in day-to-day life. From a design standpoint, the study focused primarily on how such technology can be incorporated into designing the living environments of older adults with memory and mobility issues. As the human need for and interaction with technology increases, the need for incorporating technology into the design of environments increases as well.

In this study, a proof of concept of the proposed system for a hybrid space was developed, and the user perception of the technology was gauged by using a small number of participants. While acknowledging the low number of participants, the results of the study suggest that the older adults who took part in the study were very open to the idea of using such an AR object location and information system based on visual and spatial organization hosted on electronic mobile devices to enhance their living environments. Extending the study to a larger number of participants is required to generalize this finding. The participants' responses provided feedback confirming that they found the system to be useful as well as user friendly.

This type of AR technology contributes a new dimension with regard to designing hybrid spaces in interior environments. Designers are accustomed to designing in three dimensions and are often bound by the limitations posed by the building construction materials. However, AR adds a new layer to the environment allowing designers to utilize it in their designs. For example, as shown in this study, overlays can be added to the environment to provide tags and labels. These tags and labels could be utilized by designers as design elements, the same way that signage on buildings is designed. Furthermore, it might be possible to use these AR overlays to change even the color and texture of interior environments. However, within the scope of this study, the researchers did not explore designing interior elements in these participants living areas.

Systems such as these could be implemented in assisted living facilities or in the older adults' own homes. After setting up the initial system, the individuals or caregivers would be able to help in updating the system by adding new data. The current iteration of the system did not extend to this interface to upload information, though, as it was not within the parameters of the study.

6. Limitations and future directions

As with many research projects, one of the main limitations of this study was the number of participants. Although we were unable to extrapolate any meaningful statistical data from the limited number of participants with which we tested the system, the study succeeded as a step towards testing a similar system with a larger number of participants, as well as exploring a proof of concept AR system that can be used with older adults.

We hope to develop the system further, with the input that was received from the participants and to then test it with a larger number of participants focusing on the user experience attributes. In future iterations of the study we will repeat testing the system by organizing multiple scenarios spread over a period of time rather than use 5–7 minutes for the testing.

Parallel to the current project, a prototype system was developed for the smart glasses Epson Moverio BT-200 to be used on an android mobile platform. Future directions will include testing this system with wearable devices, such as smart glasses, so that wheelchair users and other physically challenged individuals, such as those with low vision, arthritis, or limited use of hands, can also use the application and fully benefit from its features.

Conflict of interest

None to report.

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