An independent shopping experience for wheelchair users through augmented reality and RFID

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ABSTRACT

People with physical and mobility impairments continue to struggle to attain independence in the performance of routine activities and tasks. For example, browsing in a store and interacting with products that are located beyond an arm's length may be impossible without the enabling intervention of a human assistant. This research paper describes a study undertaken to design, develop and evaluate potential interaction methods for motor-impaired individuals, specifically those who use wheelchairs. Our study includes a user-centred approach, and a categorisation of wheelchair users based upon the severity of their disability and their individual needs. We have designed and developed access solutions that utilise radio-frequency identification (RFID), augmented reality (AR) and touchscreen technologies in order to help people who use wheelchairs to carry out certain tasks autonomously. In this way, they have been empowered to go shopping independently, free from reliance upon the assistance of others. A total of eighteen wheelchair users participated in the completed study.

Author Keywords

Human Centred Computing, Accessibility, Wheelchair Users, Augmented Reality, RFID

INTRODUCTION

Today, people who use wheelchairs generally inhabit an environment much better matched to their circumstances than in the past as a result of progressive legislation around the globe aimed at supporting diversity such as the Equality Act (2010) in the UK or Section 508 in the USA.

Continuing improvements in levels of independence for daily activities are regularly made as a result of advances in technology, and the general trend towards greater inclusion in society. For example, it is now common to find reserved sections for wheelchair users in car parks, on public transport networks, in restaurants, tourist facilities etc. Around the globe barriers are being addressed for wheelchair users with regards to accessing physical locations hitherto out of reach. However, in performing some routine activities, people with physical and mobility impairments continue to face significant obstacles [34]. For example, quotidian shopping activities often represent a barrier to wheelchair users since it may be very difficult (if not impossible) for them to interact with products presented on a shelf beyond reach from their seated position. In such scenarios, wheelchair users may visit stores that purportedly support wheelchair access, but in practice they may discover that they cannot reach specific products without the assistance of others. This profoundly affects their autonomy and sense of independence. Figure 1 below illustrates this common scenario of inaccessibility and demonstrates a key motivation for the undertaking of this investigation.

The aim of this study was to address this issue in collaboration with an organisation that supports people with significant motor impairments in Barcelona, Spain [1]. Under this research platform, an initial user study returned two key ideas:

1. Wheelchair users want to go shopping independently, even though it may be very difficult for them to interact with the products on sale in a store.
2. Different degrees of impairment results correspond to different user requirements. Thus, a specific and tailored solution is required for each user group.

We identified three main user groups that led to three independent scenarios built around the same concept of a radio frequency identification- (RFID) enabled smart shelf, and the utilisation of an augmented reality (AR) interface, allowing users to virtually interact (i.e. check product properties such as price or expiry date) with items in the store in real time without necessarily requiring intervention from others. The final prototype experience proved close to that of online shopping but in the context of a brick and mortar store - an approach that may also have the advantage of improving the shopping experience for the general population.

In this paper we summarise the main achieved milestones during this project:

- *A preliminary case study on wheelchair users to extract basic requirements for independent shopping.*
- *The design and implementation of three interaction methodologies based on RFID-enabled smart shelves and different interfaces (including AR technologies and touchscreens), intended for three groups of users with differing degrees of motor impairment.*
- *The involvement of eighteen potential end users in the requirements definition and preliminary evaluation stages.*

The remainder of this paper is organised as follows:

“Related Work” identifies and assesses previous studies. The section titled “Initial User Study” provides the detail of the initial user study undertaken, leading to the use cases design detailed in “System Design Based on the Initial User Study”. The final scenarios implemented in this study are detailed in Section “Implemented Use Cases and Interfaces”. Finally, Section “Preliminary System Evaluation with Users” shows a preliminary evaluation over real end users, and Section “Conclusion and Future Work” closes the paper and suggests future directions for research.

Figure 1. Wheelchair users are unable to interact with the items on the shelf which are beyond their arm's length.

RELATED WORK

Currently around 1% of the world's population use wheelchairs [4, 3]. Access and facilities for wheelchair users to shops, services and city centres are steadily improving. Cities are designed, or are being redeveloped, to consider the distinctive needs of wheelchair users and others with mobility impairments. Shops are similarly adapting to these customers' needs by providing lower height shelves, and wide spaces in aisles to improve access for wheelchair users. Mart carts (shopping mobility scooters) can also be found in some shops and supermarkets, along with attachable trolleys for wheelchairs. Staff members in-store are often trained and available to provide assistance to people with mobility impairments.

Despite these welcome developments, a majority of wheelchair users (61%) still encounter difficulties and feel that they are disadvantaged by the manner in which shopping environments are planned or designed [34] [35]. Wheelchair users often describe the need to request that friends, family members or a personal assistant accompany them when faced with the prospect of shopping in a physical store, so that they have someone to assist them in interacting with products located beyond their reach.

Researchers and practitioners are trying to empower mobility-impaired people in order to address these environmental barriers. They are working on improvements to wheelchairs by equipping them with high technology resources and providing solutions to improve levels of social inclusivity. The research community is working hard to facilitate the interaction between physically impaired people and their surrounding environment, and to grant universal access to information [21]. In fact, numerous projects have been undertaken to foster infrastructural solutions that can monitor and assist people with physical disabilities [31].

Proença *et al.* [26] developed a system that allows wheelchair occupants to gain access to certain objects present in their vicinity by using computer vision techniques and pattern recognition. An interesting work has been presented by Caon *et al*. [10] that proposes different interaction possibilities for wheelchair users through gestures and smartphones. For gesture recognition functionality the authors employed a Kinect visual camera. While this is an interesting system and scenario aimed at helping wheelchair users, it does not provide sufficient application in terms of retail and shopping tasks, where many similar stock in/stock out products become impossible to identify with current computer vision techniques.

Another project is the shopping assistant with an interface for wheelchair users presented in [8], a system designed to help those in wheelchairs during shopping without the assistance of others. This system proposed an extra cylindrical basket that could be lined with normal shopping bags for the easy transportation of goods. This enabled wheelchair customers to remain *in situ* on their wheelchairs while shopping.

The article at [18] presents a robotic system that offers increased control functionality for disabled users. This system comprises an electric wheelchair equipped with the robot arm MANUS.

Similarly, a robotic arm allowing the user to autonomously collect a desired object from a shelf has also been developed [32]. The object's position is identified using stereoscopic vision technology via a feed from a camera placed on the user's shoulder. Although this is an interesting and innovative solution, it lacks practicality, consuming very high levels of resources and thus making it impossible for wheelchair users to integrate into their everyday lives.

RFID is becoming an essential part of the retail industry because of the properties it facilitates such as automated stock counting, localization, antitheft applications etc. The tags contain item-based electronically-stored identification data. Unlike a barcode, the tag does not need to be within the line of sight of the reader, and may be embedded in the tracked object. RFID provides some advantage over computer vision solutions since it can identify individual items without direct line of sight, and also hidden products. Items with little or no difference in their outward appearance can also be identified and tracked by RFID technology - for example, clothing with the same color but in different sizes. In addition, with the increasing commercial value of the RFID market, many researchers in different domains have begun exploiting this technology in recent years. In [27] and [28] the authors have proposed an RFID-based system that allows wheelchair users to interact with products on shelves while remaining seated through different AR technologies. Välkkyenn *et al.* [33] introduced the concept of physical browsing using a mobile terminal and RFID. Kahl *et al.* [16] presented an implementation of dual reality in a retail store using RFID, among other technologies. Chen *et al.* [11] presented a similar system, but using computer vision instead of

RFID. In the following sections, we summarise our research on interaction interfaces for wheelchair users based on user participation in design and evaluation.

In [7], Biswas and Langdon organised wheelchair users into different categories based upon their hand strength, and using this distinction evaluated numerous different kinds of interfaces. For our current research we similarly identify a taxonomy of wheelchair users (see the following section for a description) and propose a set of interfaces viable for each category therein.

Considering the state of the art, we elected to employ technologies that are readily available and commonplace in retail during our daily life routines. We proposed a system to take advantage of RFID tags since this technology has already become a major player in the retail industry, alongside smartphones, heads-up displays (HUDs) and touchscreens. The use of popular, commonplace technologies can help disabled people to escape stigma [29, 20, 36]. With this approach we can also provide a valid and practical solution to wheelchair users to enable them to shop independently with minimal resources.

INITIAL DATA GATHERING

Although empowering wheelchair users to perform everyday activities is a basic requirement, the specific needs and features of independent shopping must be rigorously defined in order to find the optimal technological solutions. To achieve this goal, we invited the participation of nine volunteers from a nonprofit social solidarity organisation for people with motor disabilities that partnered our research in Barcelona, Spain [1] plus nine additional wheelchair users. Since hand mobility is known to be critical to interaction, we classify our users based upon this attribute [19, 7]. Table 1 shows the identified groups of mobility-impaired people along with categories classified by World Health Organization, International Classification of Functioning, Disability and Health (WHO ICF). With an average age of 45, participants had different degrees of impairment, as detailed in Table 2.

Group	Identified Concepts	ICF categories
H1	Requires wheelchair to maintain mobility	d465: Moving around using equipment
H2	Requires wheelchair to maintain mobility Poor hand movement, i.e. tremor, low grasping power	d465: Moving around using equipment d440: Fine hand use
H3	Requires wheelchair to maintain mobility Poor arm and hand movement	d465: Moving around using equipment d440: Fine hand use d445: Hand and arm use

Table 1. Participant's categories and ICF classification

It is worth noting that user groups H2 and H3, besides mobility reduction, may also have communication difficulties (i.e. because of degenerative illness).

Each volunteer was interviewed regarding their daily activities, shopping patterns (domestic and leisure shopping), assistance requirements and technology acceptability. The purpose of the interview was to analyse the subject's condition and requirements with respect to shopping and technology acceptability. Inductive content analysis [14] is used for the evaluation of our study. Below we summarise the salient points gleaned from these interviews:

- *16 out of 18 subjects reported a need for assistance when shopping or browsing.*
- *H1 (8 participants) declared themselves as regular shoppers, while H2 and H3 (10 participants) went shopping only occasionally or rarely.*
- *H2 and H3 participants reported embarrassment when trying to communicate their needs with store staff due to their communication problems, leading to an unsatisfactory experience.*

- *Independence and privacy are the most desired shopping experience features, and technology acceptability increases if these features can be provided.*

Subject	Gender	Age	Severity	Shopping	Technology
S1	Female	26 - 35	H1	Usually	Yes
S2	Male	26 - 35	H1	Rarely	Yes
S3	Female	36 - 45	H2	Rarely	Yes
S4	Female	36 - 45	H1	Usually	Yes
S5	Male	36 - 45	H2	Rarely	Yes
S6	Male	36 - 45	H1	Usually	Yes
S7	Male	36 - 45	H1	Usually	Yes
S8	Male	36 - 45	H1	Rarely	Yes
S9	Female	46 - 55	H2	Rarely	Yes
S10	Female	46 - 55	H2	Rarely	Yes
S11	Male	46 - 55	H2	Rarely	Yes
S12	Male	46 - 55	H2	Rarely	Yes
S13	Male	46 - 55	H1	Usually	Yes
S14	Male	46 - 55	H3	Rarely	Yes
S15	Male	46 - 55	H3	Rarely	Yes
S16	Female	56 - 65	H2	Rarely	Yes
S17	Female	56 - 65	H3	Rarely	No
S18	Male	56 - 65	H3	Rarely	No

Table 2. Initial User Study Participants

As a general summary, despite an inherent willingness and interest in the participants for visiting stores, accessibility or communication problems remain unavoidable barriers (cf. Figure1). The users expressed an interest in an autonomous method for searching, locating and retrieving specific products from within a store. We illustrate the users' feelings with the response of one participant regarding his shopping habits:

S6 (43), *I do not like asking for help from anyone, unless strictly necessary, such as climbing stairs, or a high kerb, etc. On the other hand, I am very traditional, and I like to enter the store, and to look at the products live and physically. I would like technology to provide a means to be more independent.*

SYSTEM DESIGN BASED ON INITIAL USER STUDY

The knowledge obtained through the initial user study was used to design and implement a set of technologies specifically adapted to the requirements of each group of participants. An RFID-enabled shelf provides real time inventory and location data, while different interfaces adapt to each group of participants, depending upon their hand strength.

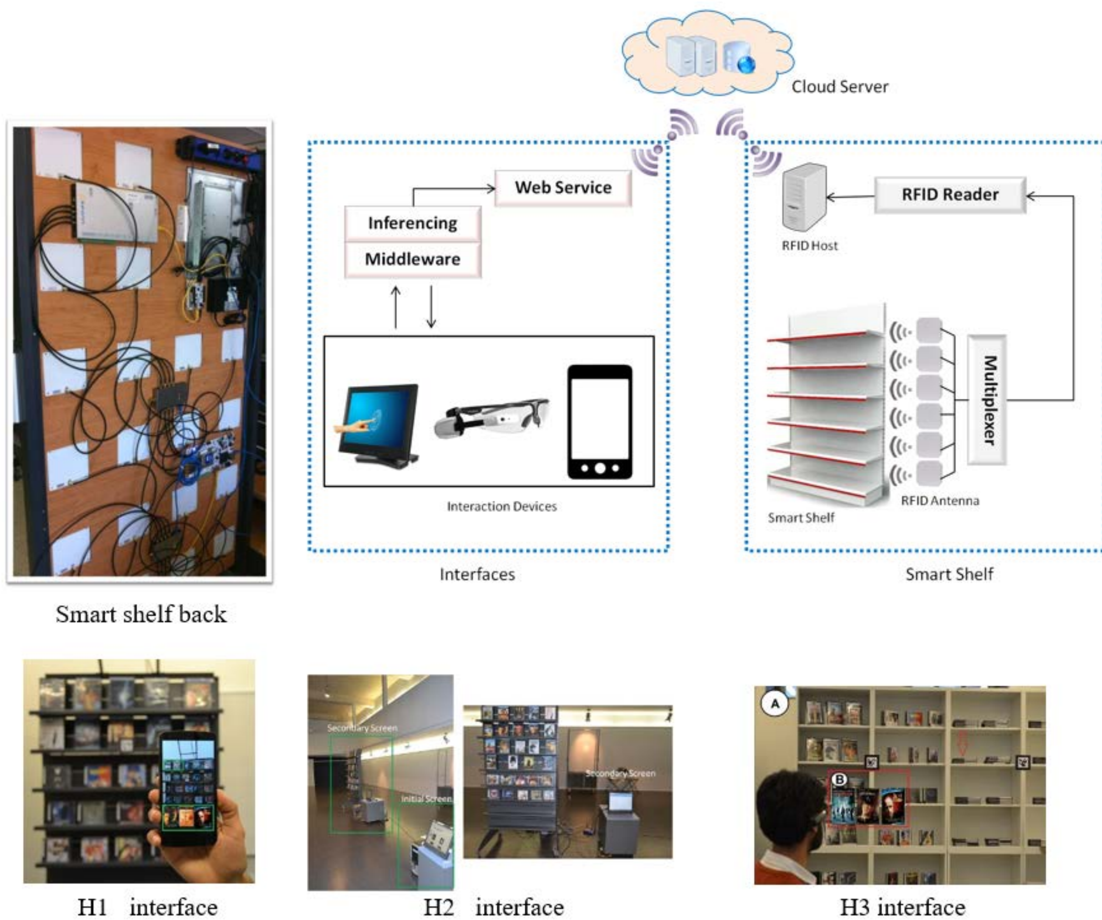


Figure 2. An RFID-enabled shelf is used to inventory and locate the products in real time. AR interfaces (smartphone and HUD) and touchscreens are used to access and interact with the product information.

SMART SPACE BASED ON AN RFID SYSTEM

Wheelchair users benefit from further information provided about the products in a store, such as availability and location, as evidenced by our initial user study. Hence, a smart space technology is required to provide such information about the items available for purchase. We propose the utilisation of Ultra High Frequency Electronic Product Code Class 1 Generation 2 (EPC Gen2 for short) RFID [15]. An RFID system is composed of electronic tags (attached to objects), a reader or interrogator and an Information System (IS) managing the system's operations. This low cost identification technology is the "de facto" standard in retail since tags are passively powered (no battery required), are cheap (under 10 cents of a dollar) and provide accurate item level identification.

We designed and developed our smart space by enabling RFID on a regular shelf with books and DVDs reproducing the scenario in [28]. The resulting system provides an inventory every minute with over 99% accuracy (less than 1 in 100 objects is missed), and a space resolution of approximately 25cm thanks to antenna multiplexing. RFID tags of different models from different manufacturers were attached to each product. The front and back view of the smart shelf is shown in Figure 2. A database within the IS stores information about each item including EPC (i.e. an ID code), an image (i.e. cover) and all available information on the package. An inventory list, containing each object's EPC, together with their approximate location is periodically uploaded to the database from the RFID system. The details of the RFID-based smart shelf system are shown in Figure 3 below.

Figure 3. A) Back of a Smart Shelf showing the RFID System. B) Frontal view of shelf with RFID-tagged products. C) Product showing RFID Tag.

Moreover, a check-in touchscreen is placed at the entrance of the pilot room to simulate the entrance of a store. The screen is connected to the IS and has access to real time information about the active inventory, location (i.e. specific shelf), and product information. This element addresses the requirement of all groups of users to have information about product availability accessible without the burden of moving inside the store only to discover that the required product is already sold out.

The interaction methodologies are designed to allow product selection, information extraction, location, browsing and purchasing. Since wheelchair users may not be able to reach the desired product, item retrieval can be performed by store staff, and collected at the check out. Moreover, H1 category users can use the H2 and H3 proposed system, and H2 users can use the H3 category proposed system. The user interface design process follows best practice for each category of motor-impaired people [7, 9, and 23]. We designed the interfaces and selected devices that are used by both typical and disabled people in order to avoid the stigma of alienation commonly experienced by wheelchair users [12, 20]. The proposed interfaces can also be used for bridging the gap between the online and offline worlds by both typical and disabled shoppers [24].

INTERACTION METHOD FOR H1 CATEGORY

Motor-impaired people classified under category H1 have regular hand movement. This is the less restricted group of users, since they have full hand mobility, but cannot reach certain objects without the assistance of another person (i.e. because of the constraints of using a wheelchair). Based on the data obtained in the initial user study (cf. Section "Initial User Study) the use of smartphone or tablet devices, together with AR technology, to access information about products on the shelves is proposed. In this system, the user points their device at the shelf, where an AR marker has been placed in a central location, thus identifying the approximate dimensions of the shelf on the screen. Moreover, the handheld device is connected to the smart space IS obtaining real time information about the products on the given shelf, and its location within that shelf. This approach has the advantage that mobile devices are ubiquitous nowadays, and so privacy may be maintained by users accessing the system through their own personal touchscreen device. By pointing to a specific area in the screen, the system returns the items in that area of the shelf, and a further click on a specific product returns all the available information. Figure 2 illustrates the proposed interaction interface for category H1. Previous studies have recommended the use of smartphone and handheld devices for wheelchair users [12, 17].

INTERACTION METHOD FOR H2 CATEGORY

Category H2 users have low hand mobility (i.e. hand tremors). Since these users are generally unable to use a smartphone unaided, the solution used by the group H1 is not possible. Instead, we propose the provision of a second touchscreen next to the pilot smart shelf. The use of touchscreens with large fonts and interfaces are recommended in previous studies conducted with motor-impaired individuals [22, 7]. Figure 2 depicts the proposed interaction interface for the H2 user group.

INTERACTION METHOD FOR H3 CATEGORY

Users under the H3 category can only use their hands for a limited set of actions (e.g. to drive their wheelchair), and generally face severe communication problems. Hence, H1 and H2 solutions do not apply for this group. However, their desire and motivation for accessing and using traditional stores remains the same, as established during the initial user study.

Enabling visual access to information about items on the shelf with minimal required hand movement is the goal for this group of users. We proposed a HUD in conjunction with AR. The HUD detects the AR marker on the centre of the shelf (also used by H1 users), and shows information about the items on the screen of the HUD (thanks to the updated RFID information). Once the desired item is shown on the HUD, a voice command or hand touch on the side of the HUD selects the item and displays the available information for the product (cf. Figure2). Studies support the use of HUD technology as a viable solution for disabled people [20].

IMPLEMENTED USE CASES AND INTERFACES

In order to design the use cases, we considered offline shopping behavior and its life cycle. The life cycle for locating, browsing and purchasing a product are the basis of each implemented use case. We designed these use cases by considering the needs and preferences of wheelchair users as informed by our initial study (Section “Initial User Study). The goal is to ensure a smooth and seamless execution of the shopping life cycle for physically impaired people, as well as for the general population. Considering the average shopping environment and merging it with the wheelchair users needs described in Section “Initial User Study, different use cases have been implemented and detailed in the following subsections. These use cases provide a complete life cycle for product browsing, selection and purchase. Figure 4 shows the different interfaces.

Figure 4. A) Handheld device AR Interface. B) Touchscreen Web Interface. C) Smart Glass AR Interface

Browsing at a Particular Location

With a handheld device, the user needs to point it towards the shelf running the AR application. Then, the user clicks/taps on the screen of the device, and the information is shown at the bottom of the screen representing the user’s selected area on the shelf. If the contents of the shelf vary, these variations will be reflected in the information shown on the screen. If one of the items shown is removed from the shelf or moved to a different location, it will disappear from the screen. Conversely, if a new item is added to the location being examined, it will then appear on the screen. The latency of these changes is determined by the one-minute time resolution of the RFID system in a worst case scenario.

For touchscreen interfaces, the user can browse items through a web interface connected to the RFID system. The device screen is placed near the smart shelf and inventorying of the products commences in real time. The different categories of the products that are present inside the store and on the shelf are displayed to the user.

For smart glasses interfaces, the user needs to focus upon a particular location on the shelf for about 3 seconds. Information about the products present at that particular location will then be displayed on the screen of the smart glasses to the user, who is then able to interact with the information through voice commands or gestures. The subsequent information provides a rich user experience for the end user.

Navigation

The user is able to navigate in a horizontal and vertical direction by clicking the arrow images provided. In doing so, information about the objects present within a diameter of 20 cm will be shown to the user. The RFID-enabled smart shelf provides the information in real time about the products present on the shelf, together with their location information. A green square moves in the user-selected location on the live image of shelf in order to highlight the user area of interest.

Search

A search box is provided to search the products present on the shelf. For handheld devices, the searched product location is provided by highlighting the correct area on the shelf. Similarly, the searched product location is shown to the user via maps and a green rectangle drawn on the shelf image.

Selection and Retrieval of Items

At any time, the user is provided with an add-to-list icon on the screen. By selecting this icon, the user can amend the list of items to be purchased, then order and collect their shopping at the counter. The selected item list is constantly updated at the counter section of the store in real time. The user can call a shop assistant to retrieve browsed or selected items from the shelf at any time with the help of the assistance icon. After browsing and compiling a list of requested items, the users are then able to select the retrieval functionality appropriate their needs (i.e. either at the checkout counter, or at the same time in front of the relevant shelves).

PRELIMINARY SYSTEM EVALUATION WITH USERS

End user inclusion in evaluation is recognised as key to research success [30]. In order to evaluate the efficacy and usefulness of the proposed systems, 12 wheelchair users were invited to participate in a pilot study, where the three interaction use cases obtained following the initial user study were implemented in a laboratory simulating a section of a store with smart shelves full of products. The smart shelf had a height of 200cm and width of 100cm. A total of 150 products (DVDs and CDs) were placed on the shelf. Products were stacked in groups of five, so that only the first DVD or CD cover was visible. The remaining four products were hidden from a user perspective;

however, since the RFID technology doesn't require a direct line of sight, it was able to detect and locate all of the hidden products. Each participant followed a standard evaluation protocol [13] including:

1. Participants were required to read and sign a consent form.

2. The experiment was explained to participants.

3. Each user interface was demonstrated and explained to participants.

4. Participants were given the chance to practice.

5. Participants used the interfaces for a maximum of 30 minutes in a session.

6. Participants filled out a questionnaire regarding their experience.

Throughout the experiment users were observed by researchers in order to record any problem or impediment identified with the system's utilisation. The analysis consisted of capturing both qualitative and quantitative results. Qualitative results rely on observations and participants' opinions. For quantitative results, each user was asked to perform a selection of tasks (to include product selection, the search for a particular product, location, and the purchase of a particular product) whilst using the system, and then to rate their experience. All of the tasks were conducted in a random order (the counter balancing principle of usability evaluation [25]). Each user was given 30 minutes to interact with the products and shelf through their interfaces. After using the interfaces and completing all the tasks, each participant completed a final questionnaire, consisting of open and closed questions or statements. All of these were originally expressed in the local language (Spanish). The objective was to review satisfaction with each interaction method and interface in terms of ease of use, and also to evaluate the efficiency of the interface and the considered features. To collect this data we employed a Likert scale with points from 1 (strongly disagree) to 5 (strongly agree). The statements/questions posed included:

1. This application will enhance my independence in terms of shopping or browsing.

2. I found these interfaces useful.

3. I found it easy to visualise and interact with the product information.

4. I am satisfied with the current level of options available.

5. I enjoyed using the application.

6. I found it easy to use the application.

7. Do you have any other comments or suggestions?

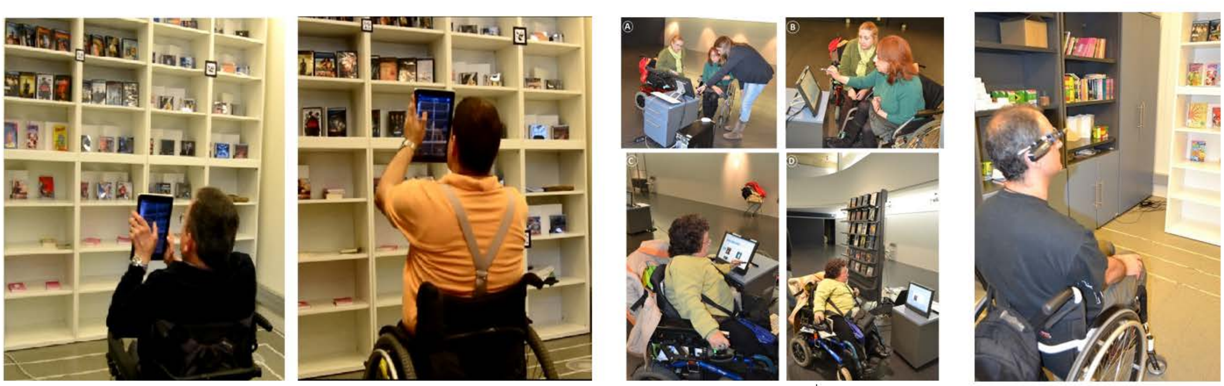
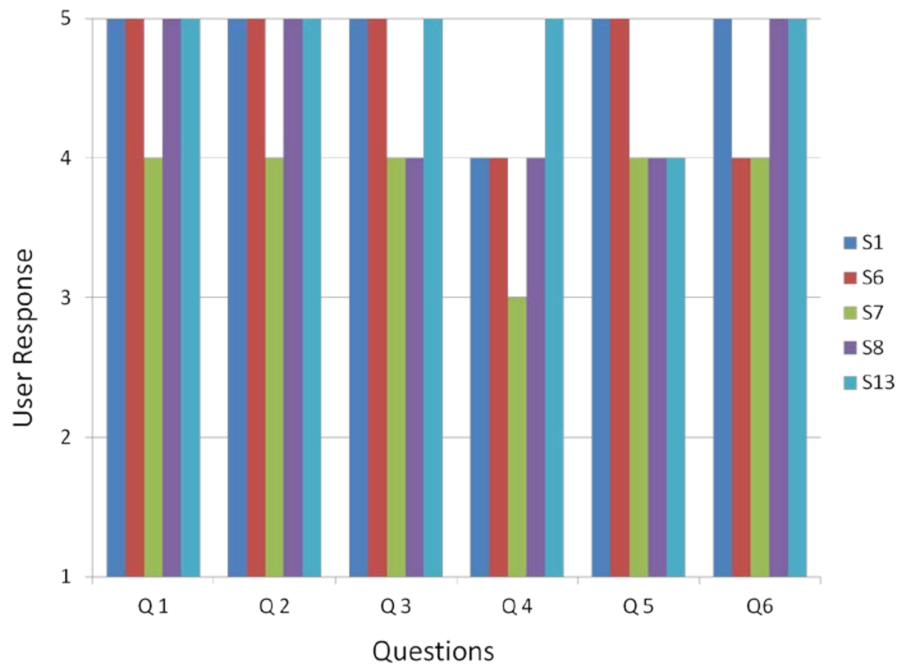


Figure 5. Twelve wheelchair users evaluated the proposed interaction systems in a laboratory environment reproducing a section of a store.

Evaluation Results for Category H1

In general, H1 category participants were very satisfied with the proposed system. Most participants gave the maximum score to the different aspects of the system. The minimum averaged score (4 out of 5) was obtained for Question 4 (*Are you satisfied with the current level of options?*) where participant S7 gave 3 points. In the comment section, participant S7 requested having the system connected to social media networks and other online options, which were not implemented in the use cases. From the answers it became clear that purchasing products with the implemented solution proved problematic for people not familiar with these technologies. However, browsing and locating products returned a higher satisfaction response from participants, as demonstrated by the questionnaire answers. Overall questionnaire responses are shown in Figure 6.



Evaluation

Figure 6. Evaluation Results for Handheld Device Interfaces.

Results for Category H2

H2 category participants were satisfied with the proposed system. Question 1 and 2, regarding the overall usefulness of the system, got the highest scores (over 4 out of 5). Questions 3 to 6, concerned with specific questions about the use cases, got slightly lower scores (almost 4 out of 5). This result demonstrates that although the system behaved correctly, the use cases design was not as well adapted to the touchscreen interface, as compared with the smartphone or tablet use cases. However, H2 participant satisfaction was slightly under that of H1 participants (see previous evaluation). H2 participants' motor disabilities affect their hands and arms and as a consequence they have more difficulties in performing the same actions as people in the H1 category. Considering how close H2 participant satisfaction was to levels of H1 participant satisfaction, this should be interpreted as a successful result in terms of human computer interaction design. Individual questionnaire responses from Category H2 are shown in Figure 7.

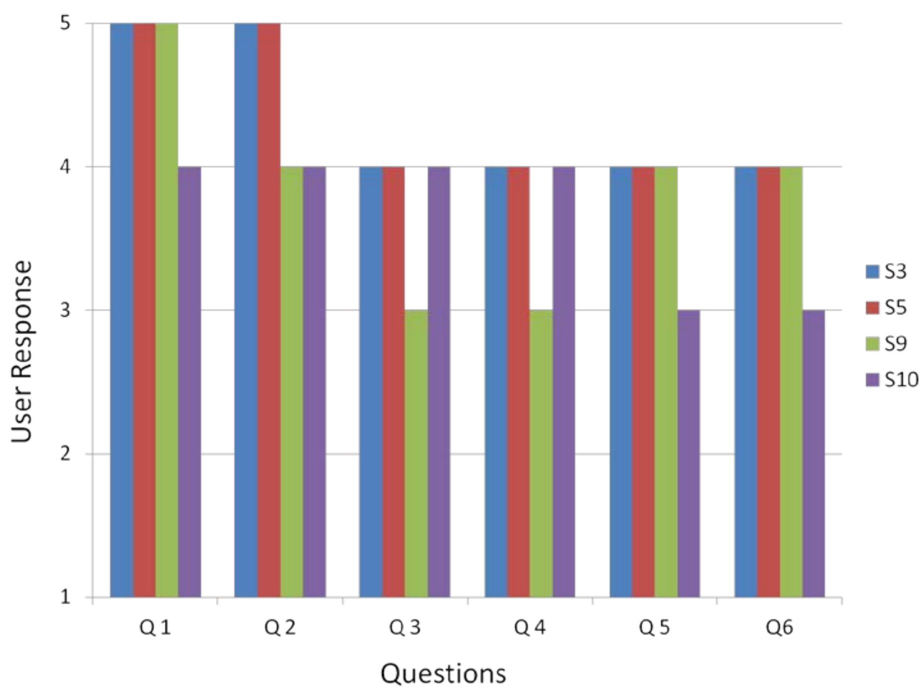


Figure 7. Evaluation Results for Touchscreen Interfaces

Evaluation Results for Category H3

H3 category participants returned the lowest satisfaction response after using the proposed smart glass use case. The participants found the use case useful in terms of enhancing shopping or browsing independence (average of 4 points out of 5). However, the participants had problems using the actual prototype (average of 3 points out of 5), as well as in utilising the respective functionalities (average over 3 points out of 5). Focusing on participant S17, she expressed the lowest satisfaction response within the H3 group. This user specified her poor eyesight, and poor arm and hand mobility as reasons for her dissatisfaction while evaluating the use case. Overall questionnaire responses from category H3 are shown in Figure 8.

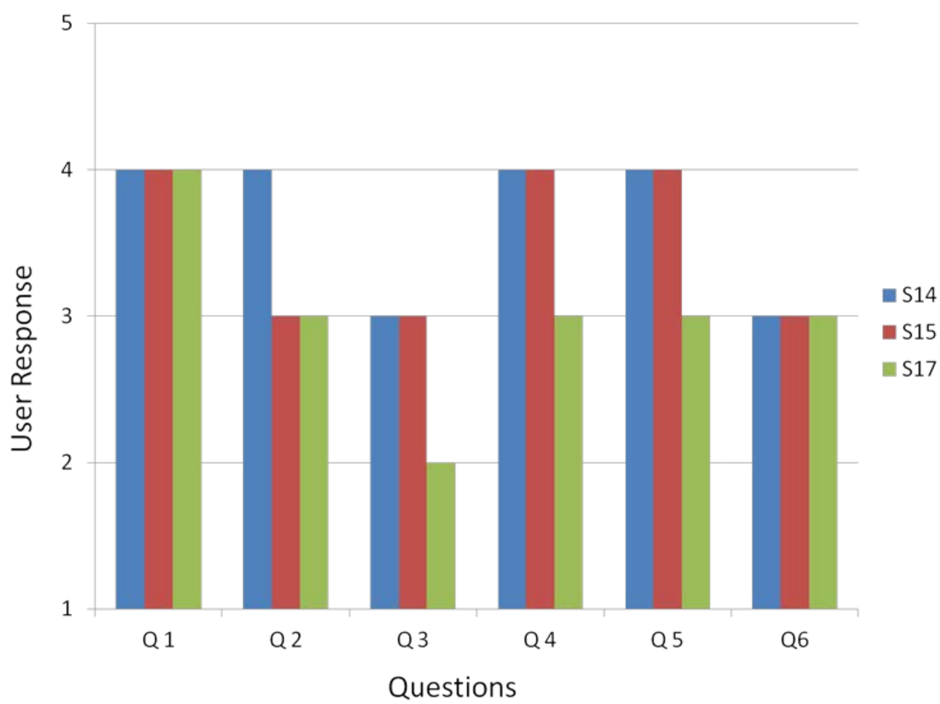


Figure 8. Evaluation Results for Smart Glasses Interface

Overall Results and Discussion

To foster a complete life cycle of shopping for wheelchair users, it is clear we must provide more accessible and adaptive shops. Shops can adjust to the needs of wheelchair users by keeping wide access spaces in the aisles between product shelves, and generally keeping wide spaces in the built retail environment for easy movement of wheelchairs and mobility scooters. Shelves should have a low height to facilitate equal access to products for customers who use wheelchairs as a mobility aid. The provision of moveable or wheelchair attachable trolleys is important. As this investigation has shown, we can also empower wheelchair users with the technological means for interacting with products inside the store. From our observations and questionnaires, we conclude that the users were able to execute the implemented use cases. H1 (5 participants) and H2 (4 participants) users successfully completed a cycle of shopping that included a search and add to list functionality from the opening screen (store entrance); to arrive at the secondary screen (close to shelf) for browsing product detail information, specific location and selection for purchase.

We initially opted to use a Samsung tablet with a 10 inch capacitive touchscreen for clarity and better visualisation of displayed information. In retrospect we hypothesise that a smartphone would have been a better choice, since it is easier for our target users to manage. While conducting user testing we noticed some grabbing and management issues with the tablet by the H1 category users while seated in their wheelchairs. Similarly, bigger screens and fonts are recommended for the H2 participants. During our experiments, we were using 14 inch touchscreens. With regards to the Vuzix smart glass use, our research revealed a number of issues. First, due to the poor hand and arm mobility of our H3 category participants, we noted that they were unable to interact with the check-in touchscreen. Second, the smart glass gesture and voice interface was difficult for them to navigate due to technology shortcomings combined with their physical impairments. During the smart glass interface experiments, participants were comfortable browsing the products from the shelf, as it involved only head movements. They were able to successfully access particular product information, but more complex interaction with this information proved a cumbersome task for them. For this reason, H3 category participants browsed many items but failed to search, locate and purchase them. We posit that more time spent by users practicing with the system would perhaps be a useful strategy towards overcoming these shortcomings.

In summary, H1 and H2 participants evaluated the overall experience as a satisfactory one. However, users of group H3 (consisting of three participants) encountered more difficulties in adapting to select products with the HUD, evaluating the experience at around 3, and also presenting acceptability issues as in [20].

Based on the foregoing results, the combination of Internet of Things technologies - including the prototype system constructed with RFIDs, smartphones or tablets, and touchscreens connected to the Internet - met the requirements identified in our initial study by our participants, i.e. the need for a tool that would empower them to become more independent and autonomous in performing everyday activities. State of the art products have been successfully integrated to test and evaluate the proposed use cases. Considering the facts that RFID technology is already being used in stores for maintaining inventories, and that smart consumer mobile devices are also ubiquitous nowadays, this supports our assertion that the proposed use cases could be deployed in the short term. Figure 5 shows the different user groups interacting with the system.

The technologies we used in the system are state of the art technologies and readily available. RFID is very common in the retail environment, and smartphone usage continues to rise. Our system also has the potential to be used by the general public for bringing online shopping features to the offline retail market. In addition, the use of the system by all shoppers helps wheelchair users to feel more integrated, bolstering inclusion and providing a welcome step closer towards the support of diversity and social cohesion.

Finally, it is worth including some open thoughts from the evaluation participants, regarding their experiences and sense of satisfaction with the proposed system:

- *After using the system, I can say that it will be beneficial for everyone in wheelchairs because it is necessary for us, and apart from this, all retail (e.g. supermarkets, shops) should incorporate it.*
- *I think the system is interesting, especially for buying products independently. It is interesting to know and get information about products that was not possible before.*
- *Current experiments have been done with CDs and DVDs, which is interesting. If the same system would be implemented for shops and supermarkets that include clothing and items we consume every day, it would be great for people in wheelchairs. For day to day activities, and all purchases people do in wheelchairs, this technology helps us to attain our independence and maintain our privacy in any store, without needing help, and would result in gaining personal autonomy.*
- *These interfaces are helpful to me to do shopping by myself without asking or requiring the assistance of other people. I would like to have it available at real shops, and think that getting used to something like this is very easy, and it is an opportunity to be more independent.*

CONCLUSION AND FUTURE WORK

Technology has the potential to be a powerful tool for people with mobility impairments to promote and support independence in their everyday lives and activities. We presented an initial user study with 18 potential end users, and provided a solution to three different scenarios that fit to their specific disability needs, using RFID-enabled smart spaces, AR over smartphones or tablets, HUDs, and interactive touchscreens. A preliminary evaluation shows promising results in promoting independence and autonomy for wheelchair users in routine activities such as shopping.

Future work we suggest includes improving the proposed use cases based on the user evaluations undertaken and reported in this paper. We also plan to improve the prototype's user interfaces based on the obtained results, and explore alternative means to AR for presenting product information to customers. In order to simplify the interaction on a tablet, a freeze function will be introduced so that the user will be able to freeze a point of view and interact with it, without the requirement of holding the device facing the shelf. Next, we plan the implementation and evaluation of the proposed systems and interfaces in a commercial retail store. That is, providing the users with the necessary information for the products available in the store by means of technologies both remotely and on site, to allow any citizen to perform the common daily activity of shopping autonomously, irrespective of their condition. Moreover, we plan to extend the proposed technologies to support other groups of people with disabilities by adapting the proposed interfaces appropriately and as required.

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