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VirtualEyez: Developing NFC Technology to Enable the Visually Impaired to Shop Independently

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Abstract **-** VirtualEyez is a low-cost mobile system that uses NFC tags (NTAG 203 tags) to help visually impaired people shop in a grocery store. While the main purpose of this system is to provide visually impaired people with greater independence when grocery shopping, anyone can use VirtualEyez to navigate a store and obtain product information. The prototype was designed to check product availability, generate optimal directions to products, and provide product information. In this paper, we describe the VirtualEyez system and discuss the results from a preliminary study where participants (visually impaired, partially impaired, and sighted) tried the prototype in a mock grocery store.

Keywords**:** NFC technology, visually impaired users, blind users, grocery store.

1. Introduction

According to the World Health Organization (2012), there are currently 285 million blind and visually impaired people worldwide, 39 million of whom are considered legally blind and 246 million of whom have sufficiently low vision to be considered visually impaired [1]. Visual impairment has increased in prevalence over the past three decades, with 90% of visually impaired people living in developing countries [1]. However, visual impairment is common in developed countries, as well. The Canadian National Institute for the Blind (CNIB) has reported that, every 12 minutes, someone in Canada begins to lose his or her eyesight. According to the CNIB, the widespread occurrence of vision loss makes it "very likely that you or someone you love may face vision loss due to age-related macular degeneration, cataracts, diabetes-related eye disease, glaucoma or other eye disorders" [2].

Most visually impaired people have difficulties not only with things like reading, but also with basic daily activities such as riding the bus, identifying locations, and purchasing groceries. Not surprisingly, there is a great desire among visually impaired people to become more autonomous so that they can accomplish these tasks independently and without human assistance. Nonetheless, it is common for visually impaired people to relinquish responsibility for personal finances, shopping and the like, and they are often thought by sighted people to be unable and/or unwilling to accomplish everyday tasks on their own. In reality, most visually impaired people strive to gain or retain independence in their daily lives and to seek hobbies and interests that will allow them to lead a full life. Indeed, as one participant, who has been blind since the age of seven, has stated, "independence in one's daily activities, without requiring/requesting assistance from a sighted person, is of the highest priority" [3]. This emphasizes the need to build systems that help visually impaired and blind people become more independent.

One activity that the visually impaired finds challenging is shopping, as blind and visually impaired people are often unable to find the items they want in stores. Many retailers offer online shopping, but this process may be difficult and time-consuming. For example, visually impaired people have to listen to all possible choices before they can choose the product they want. Even worse, if they miss the item they want, they have to listen to the entire list again [4]. Some organizations also offer home delivery, but even when available, the service sometimes requires the customer to make an appointment. These alternatives limit personal autonomy and make independent shopping difficult. As a result, blind and visually impaired people often avoid procuring these services at all, further degrading their quality of life.

To shop in a grocery store, blind people often have to ask a grocery employee for help or hire someone to assist them

[5]. Not all grocery stores assign an employee to accompany a person with vision loss around the store, and hiring an assistant can be expensive. In short, the currently available solutions for these problems related to visual impairment are not satisfactory.

This paper will describe the development process of a smart technology designed to enable visually impaired individuals to shop at their own convenience using an android phone with Near Field Communication (NFC) tags. Typically, the utilization of smart phone features by the visually impaired has been very limited due to the user interfaces only being accessible through LCD screens [6]. Although they may need to memorize functions or rely on sighted assistance for some features, many visually impaired people own and use smart phones [6]. With the addition of appropriate accessibility services such as speech-access software, people with visual disabilities are better able to navigate between the applications and interfaces [6].

Our system, called VirtualEyez, helps visually impaired individuals navigate a store to help them locate items of interest. It indicates the shortest route to reach the product being sought, which also makes this system potentially useful not just for the visually impaired but for any shopper. The system also provides product identification and information (e.g., price) after the customers have reached their desired items.

The rest of this paper is organized as follows. We discuss the related work and then describe the system design for developing an NFC application. As well, we outline some general results from the initial evaluation of the system by real users (sigted and visually impaired). Finally, we present the conclusion and possible avenues for future work.

2. Related Work

2.1. Assistive shopping systems

Many different types of assistive shopping systems have been developed to help blind and visually impaired people grocery shop independently. For example, Robo-Cart uses a robotic shopping assistant [7]. It guides users in a grocery store using a Pioneer 2DX robot embedded with a laser range finder and RFID reader to navigate the visually impaired shopper to the location of the products. The robot follows line patterns on the floor with the scanner's camera to navigate within a grocery store, and the shopper uses a hand-held barcode scanner to identify a product. Installing lines on the floor of stores is a reliable and inexpensive alternative to using RFID tags [7] [8].

Ivanov [9] developed an indoor navigation system combining mobile terminals and a Java program with access to RFID tags. It offers a map of the room that includes dimensions and the relative positions of points of interest. In this application, RFID tags contain the building information. The system permits audio messages that are stored in RFID tags and recorded in the Adaptive Multi Rate (AMR) format to enable visually impaired individuals to listen to the direction commands after touching the tags. The advantages of this system include that the locations of RFID tags are easy to find because the tags are located near the door handles, with each door serving as a reference point for all points inside the room. Each tag has information about the location of all reference points inside the room. This system also allows blind users to rely on their white cane to overcome any obstacles in their way. It supports audio navigation and interacts with users' movements in a reasonable amount of time. The major disadvantages of this system are that it requires a web server and the cost of the RFID tags is too high for most visually impaired or blind people, whose incomes are generally modest.

An assistive shopping system that is relatively low-cost is BlindShopping [10] [11], which is a mobile system that uses an RFID reader embedded on the tip of a white cane to guide users at a supermarket. The RFID tags are attached to the supermarket floor. It also uses embossed QR codes posted on product shelves to enable users to use their Smartphone camera to recognize and identify products of interest. For system configuration, BlindShopping requires a web-based management component that produces barcode tags for the shelf [10] [11]. The main advantage of this system is that a supermarket does not have to go through costly and time-consuming installation and maintenance processes. As well, users who use the BlindShopping system do not need to carry additional gadgets. However, it is difficult for blind people to use a mobile phone to read QR-codes because it requires direct line-of-sight and precise direction. Additionally, a blind user must send the product image to a remote database on the Web to identify it, which requires both a significant amount of time and Internet access, the latter which can be costly for some individuals and the former which can be frustrating.

iCare [12] uses an RFID reader attached to a glove to help users find what they need when shopping. The system uses Wi-Fi to connect to a product database. Each product also has RFID tags so that visually impaired people can read product names simply by touching the product with the glove [12]. Similarly, Trinetra [3] is an identification system that uses a Windows-based server, a Nokia mobile phone, a Bluetooth headset, a Baracoda IDBlue Pen (for scanning RFID tags), and a Baracoda Pencil (for scanning barcodes). In handling both barcodes and RFID tags, Trinetra enables customers to use whichever identification technology is available. The overall objective of the Trinetra system is to retrieve a product's name when the user scans a barcode tag, helping the user to recognize and identify the item. The system does not support indoor navigation features, which means the user is responsible for finding the product's target location. In fact, the user does not have the ability to perform an efficient search for a target product location. For example, if a supermarket has 45,000 products, it may not be possible for the user to find a specific product in a supermarket without any navigation route or search directions.

There have been some recent examples of NFC-associated systems being designed for use in different areas. For example, Mobile Sales Assistant (MSA) [13] has been implemented in a clothing store. This system combines NFC and the Electronic Product Code (EPC) to optimize and speed up the sales process in retail stores by permitting customers to check the availability and supply of products at the point of sale. MSA may increase customer satisfaction as well as sales. Another example is a system called HearMe [14], which is used to assist visually impaired and older users to identify medication and product information (e.g., dosage) by transforming information from the package (encoded in NFC tags) into speech [14]. This app reduces the reliance on medical employees and family members to remind the patient of scheduled medication. Similarly, the French supermarket chain Casino has examined using NFC-enabled phones to help customers easily acquire product information (e.g., product name, price and ingredients) by reading the stored information on NFC tags [15]. However, because there is no indoor navigation system, customers have to touch products in the supermarket randomly until they find what they are looking for.

3. System Design

The VirtualEyez system was developed using:

1. A Google Nexus 7 tablet with an Android 4.3 platform as an NFC reader
2. Passive NFC tags (NTAG 203 tags) deployed on every top shelf in the grocery store, 100 cm apart from each other, and at the entrance/exit (Figure 1), and a database containing product information and product location tables.

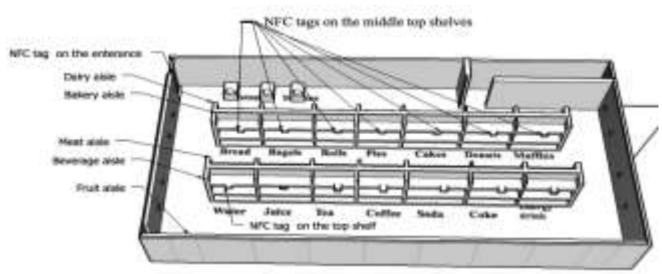


Fig. 1: Locations of NFC tags.

NFC tags serve two essential functions. First, they allow for an automatic launch that eliminates the need for users to figure out where the app is on the mobile screen. Second, NFC tags allow the application to identify and keep track of the shopper's current location. To acquire this information, the mobile device will read the content of the NFC tag (Point ID) and send it to the app as a source node.

3. A SQLite database that stores the building's layout (geometry for each position point in the floor of the grocery store) as well as the products available in the grocery store. The system uses an SQLite database to keep track of relational data associated with the NFC tags. For instance, the NFC tag with the ID 3 was associated with the section named "Tea". The database has a point table with grocery store map information, which contained one row for each NFC tag. These rows have columns for the point ID (NFC ID), the location name, and the point's neighbors (the upper point, left point, right point, and the down point). The NFC with identification code 3 also connected to 3 rows in product table. This means that each row in the point table is connected with 3 rows in the product table.

The VirtualEyez system's operating procedure consists of four fundamental functions: input of the item name (via voice recording or the phone's keyboard), check of its availability, navigation within the store, and product identification.

The following subsections discuss the assumptions and VirtualEyez system functions in greater detail.

3.1. Assumptions

The VirtualEyez system was designed based on the following assumptions:

- The virtual store in the CNIB center would be built using groups of bookshelves organized as aisles (seven bookshelves per aisle).
- Visually impaired people could use a guide dog or a cane to enable them to identify any obstacles in their way.
- NFC tags would be posted in areas that are prominent and touchable to enable participants with vision loss to find the tags easily just by touching.

3.2. System Functions

3.2.1. Inputting and checking the availability of the desired product

This task is achieved by carrying out four sequential steps (Figure 2). Each step is critical to checking availability, and the steps are interdependent. After the shopper inputs his desired item, the application will immediately perform the remaining three steps. These four steps will be explained in detail in the following subsections.

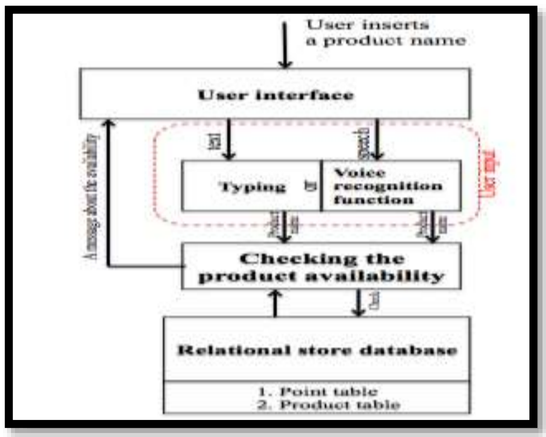


Fig. 2: Checking the availability of the desired product.

Step 1: Enable customers to input their item

This application provides two options for the shopper to insert his/her desired item. It enables the customers to record their desired items via voice recognition, with customers speaking to their Smartphone devices in order to record their chosen items in the SQLite database. By using the speech-to-text service, the voice of the shopper will be converted to text. The second option is that the customers can type their selected items using a Smartphone keyboard. If the visually impaired shoppers prefer to use this option, they should use the TalkBack service.

Step 2: Send the inserted product to the database

After recording the desired item using voice recognition, the application will immediately send the inputted name to compare and match it with a product name in the store database.

Steps 3 and 4: Check the availability of the chosen item and retrieve an alert message

After sending the chosen item, the app accesses the store database to check whether the desired item is in the grocery store or not. If the item is not in the database, the application will deliver the message “The product is not in the store.” If the desired item is in the database, the application will receive the alert message “The item is in the store”, which confirms item’s the availability. At the same time, the text-to-speech service will read aloud the alert message for the benefit of shoppers with low vision. In immediately checking whether the product is on hand, this step minimizes wasted time. The application then presents the location of the item on a map and verbally states the direction commands.

3.2.2. Indoor navigation system function

The VirtualEyez application also provides indoor navigation guidance using NFC tags. This function begins immediately after receiving the result (an alert message) that the product in question is available. At that time, the application allows a shopper to receive direction commands to his/her selected item. The shopper can also update his/her direction commands by tapping the NFC tags, which are located throughout the store, enabling the application to obtain the user's location and update the route. In addition, the application allows the shopper to know where he is, speaking the name of the section when an NFC tag is tapped. The indoor navigation system has four steps: Some of these steps rely on the input value (product name) provided by checking the availability function.

Step 1: Scanning NFC tags

Each NFC tag has point position information, which is written using the Tag writer application. Any NFC-capable mobile device, in reading the contents of NFC tags, will acquire the user's location. For example, in the milk section, an NFC tag would be located on the top middle shelf. The user has to tap his/her NFC device near the tag to permit the reader to read the content of that tag.

Step 2: Retrieving the location of the chosen item

After sending the NFC ID (source node) and the name of the chosen item (product name) to the app, the desired item's location information (node coordinators) will be downloaded to the mobile phone from the grocery store database.

Step 3: Applying routing algorithm

The routing algorithm used in this application is Dijsktra's algorithm, which is used for finding the shortest route between two locations. A route between two points will be represented by an array matrix, which has all the possible points that the route, from source to destination, will pass through. The application receives the input values (source node, destination node) in order to perform the Dijkstra algorithm. This process will be described in the following sub-sections.

Step 4: Representing a visual or audible map

After determining the best route, the system returns an array list with the nodes that should be passed through in order to reach the destination. For example, if the user is at the store entrance and wants to buy milk, the algorithm will return an array list that contains [gate (0,0), diary product aisle (1,3), milk (2,3)]. VirtualEyez provides navigation guidance by combining visual and audio directions during navigation inside a grocery store. While low-vision and sighted people can follow both visual and audio directions, blind shoppers are entirely dependent on audio direction.

A visual map is the most important element in a navigation system, as it allows the user to easily see his/her current location and the path to his/her destination. We have used a two-dimensional map, in that the grocery store has been represented as an image with nodes and edges. Thus, each location in the store is represented by a node indicating positional information, and between any two points there is a line that represents how the shopper can move from his current location to his destination. As shown in Figure 4, the grocery store map has six aisles and seven sections in each aisle, so that there are seven nodes in each aisle.

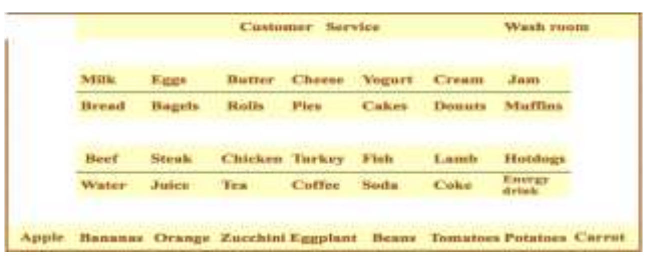


Fig. 4: Grocery store map.

The user interface of the indoor map system facilitates high usability of the indoor navigational system through the functionality of displaying the store map and finding the optimal route. The map is represented in a simple way so that shoppers can see the whole store, and the route between the current location and target item is represented with a bold green line to enable people with low vision see the path clearly. Figure 5 shows that after applying Dijkstra's algorithm, the On Draw function will receive all of the point coordinates that the user has to pass from his current location to the selected item. The On Draw function will receive all of the point coordinates that the user has to pass from his current location to the selected item. The On Draw function uses the two-dimensional grocery store map image as a background and then draws a line on top of the image based on the point coordinates from the source node to destination.

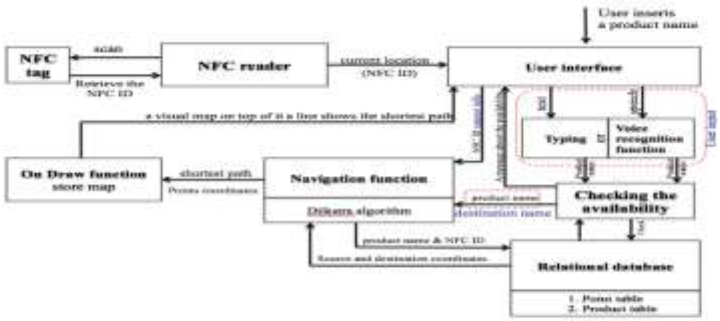


Fig. 5: Indoor navigation system generates a visual map.

The application provides the direction commands as a two-part text message. The first part has the name of the selected product, as well as the name of the aisle and position of shelf (bottom, top, or middle) containing the product. The second part of the message has the direction commands (go ahead, turn left, and turn right) from the current location to the selected item. VirtualEyez also provides an audio map in order to assist people with no vision. In order to obtain the audio map, the TTS service is employed in order to read the text message.

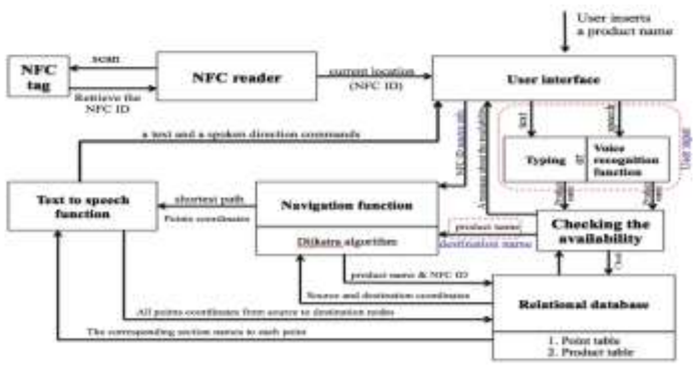


Fig. 6: Indoor navigation system generates an audible map.

Figure 6 presents the result of applying the Dijkstra algorithm to find the shortest path from the source point to the destination point. It shows an array containing all point coordinates that the user has to pass to move from his current location to the selected item. This result is an input into the text-to-speech function, thus the TTS function will fetch the corresponding section name to each point coordinate. The TTS then sends the direction commands to the user interface as both text and voice.

The audio map also has the capability of informing shoppers of their exact location at any point, which is of great value, considering the limited capacity to acquire such information from landmarks. To find his or her exact location, a shopper simply taps the nearest NFC tag in order to read its unique ID, and then the app will immediately fetch the NFC ID. After that, the app will send the fetched NFC ID as a query to the store database to return back to the customer the location name that matches the fetched NFC ID.

3.2.3. Product identification

Product identification is a vital step in helping people with visual disabilities to identify their selected items. The aim of this function is to provide shoppers with confirmation that they have reached the correct section and, more importantly, have selected the correct item.

Figure 7 shows that when the user taps the NFC tag, the application will immediately read aloud the product name and allow access to relevant information about the product. When shoppers record or type the name of a desired product, the application will fetch the general information for the chosen product from the store database. Each product in the grocery store database has general information, such as price, expiry date, ingredients and nutrition facts. The application displays item information as an audio message, so shoppers with low vision can hear it. They can press the “description” button several times to hear the product information repeatedly.

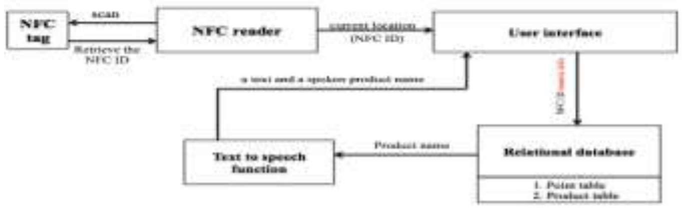
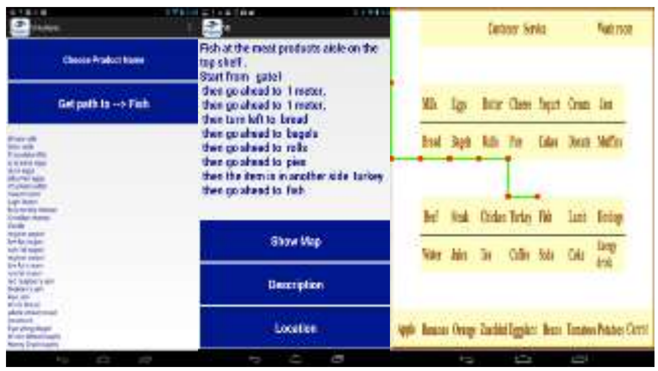


Fig. 7: Product identification function.

4. VirtualEyez application interface

The application, which is installed in a shopper's android device, has three sequential views (as shown in Figure 8), each with a particular function.



(a) (b) (c)

Fig. 8: VirtualEyez interfaces.

The first interface shows two large buttons labelled as "Choose product name" and "Get path". Clicking on the "Choose product" button in the VirtualEyez application interface (see a) brings the user to the recording screen, which runs the speech recognition service from Google, enabling customers to record the name of a desired item. In response, the application will retrieve an alert message to inform the customer of the selected item's availability. By clicking on the "Get path to selected item" button (see a), the user proceeds to the path screen. When a shopper scans a passive NFC tag, its unique ID acts as an input for the shortest route algorithm. It then fetches the source (the shopper's current location) and target item ID from the database table and executes Dijkstra's algorithm to find the shortest path. The shortest path is returned in the form of an array, which includes node IDs to be traversed in order to reach the desired item. Once the shortest path is determined, it shows as a text message on the screen (see b) or is sent to the On Draw function to overlay it on top of the map image (see c). When customers reach their selected items, they touch the NFC tag on the top shelf to confirm that they have reached the correct location.

5. Analysis And Discussion

5.1. Methodology

To examine the usability of the VirtualEyez system, we ran an initial study to obtain user feedback. We were interested in learning how useful and usable the system was for grocery shopping, and we were also looking for suggestions to improve the system. We set up a mock grocery store in the Canadian National Institute for the Blind (CNIB) office in [removed for blind review]. This mock grocery store had four aisles with several products on the shelves to make the shopping experience realistic (Figure 9). The participants were asked to buy four products, which were located on different shelves and locations within the shelves (e.g., on the top, on the bottom, and in the middle).

Nine participants took part in this initial evaluation. Before the participants started the study, they completed a demographic questionnaire and were given a training session. The participants then performed four tasks that required them to find four different products that were placed strategically on the shelves. We also had participants actually remove the items from the shelves and carry them in a bag while they found all four products. Blind participants were allowed to use any aides they normally used (e.g., guide dog or white cane). After the participants finished the tasks, they took part in a short interview on their experience. A researcher also took observational notes during the study. The study took about 45 minutes to complete. The participants had different levels of vision: two partially-sighted participants (2 males aged 38-48), five blind participants (2 males and 3 females aged 32-71) and two sighted participants (1 male and 1 female aged 29-71). In terms of previous shopping experiences, most visually impaired and blind participants said that they generally had difficulty finding specific items quickly in a grocery store and found distinguishing canned products and navigating through grocery stores particularly difficult. Sometimes they had to ask a clerk for help while shopping and they tended not to hire a shopping assistant or use delivery services, mainly due to the cost. All of the visually impaired participants used a magnifier app to enlarge the size of text on their screens, and all the totally blind used the TalkBack service to interact with their device.

6. Results

During the study, eight participants bought the four items without any difficulty and without asking for help. The participants were able to locate the right shelf for each item and were able to locate the specific item within the shelf (top, middle, or bottom) without difficulty. One participant had some difficulties, but it should be noted that this participant had both vision and hearing impairments. This participant asked for help during the tasks.

After the participants tried VisualEyez in the mock grocery store, we asked them about their experience using the system. We found that participants liked the simple features of the interface. The buttons were well organized, easy to find and remember. The totally blind participants used the interface successfully with the help of TalkBack. When navigating to products, the sighted participants preferred the visual map, while the others had to rely more on verbal instructions. They found the audio to be clear and easy to follow but too slow. Four of the participants noted they would want to be able to adjust the speed. Following the direction commands and NFC tags was easy for all participants (probably due to the fact the NFC tags were at eye level in this study).

The visually impaired participants felt that VirtualEyez would help them shop more independently and potentially faster than they currently shopped. They liked that the system helped them with product prices and labels. Many also found the location button helpful, as it told them what products they were passing by, potentially reminding them of items they had forgotten. The sighted participants also liked the app because it told them what was inside the store, so they did not have to spend time looking for items that may not be in stock.

One issue brought up by the three blind participants was that the app did not help them avoid obstacles. In a real store, there are often boxes, shelves and displays in the middle of aisles. Another issue was that blind participants had to a carry the mobile phone in addition to a shopping basket, which could prove difficult in combination with a cane or a guide dog. However, embedding this concept into existing wearable watches will eliminate these difficulties and will be more connivance. Thus, it may be necessary to reduce the physical burdens in the system in order to accommodate those with such visual aids. A related concern that was raised during this evaluation was how to provide support for individuals who have more than one challenge (e.g., sight and hearing). Maybe adding other features such as tactile output could be beneficial. We nonetheless feel that some features of VirtualEyez may benefit not just visually impaired and blind people but also sighted individuals (e.g., locating products).

It is likely that testing the application in a real store would reveal other issues and challenges. Still, while the mock grocery store was relatively small and only had four aisles, and finding four items would perhaps be much easier than finding the number of items one typically buys when grocery shopping, the test nevertheless allowed us to perform an initial assessment of the system with real users.

7. Conclusion and Future Work

NFC technology provides a reliable, low-cost indoor navigation system as well as an identification system. NFC tags eliminate much of the time delay associated with other systems because information can be transferred directly from tag to Smartphone rather than relying on access to servers and networks. The VirtualEyez system was evaluated in a mock grocery store setting, which helped us to identify the useful features of the VirtualEyez prototype and obtain feedback for improvements. The main contribution of our research is that we have used existing technologies (e.g., NFC tags and mobile devices) to create a low-cost proof-of-concept mobile application to help blind and visually impaired people overcome some of the barriers they face when grocery shopping. The initial evaluation received positive feedback and also provided some improvements for the system.

In the future, we plan to incorporate the feedback into the system to increase its usefulness. We would like to make it work with different grocery store designs and supermarket concepts. Currently, VirtualEyez has been designed for a single-door layout, but this could be extended to multi-door, multi-floor buildings, with elevators and emergency exits taken into account. We are planning to improve the application and let the customer record the list of all goods and then optimize the route when a customer has to purchase more goods. We are also examining how to add an obstacle-avoidance application, and would like to develop this system to support different disabilities (e.g., hearing impairment) and different languages.

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