VIRTUALEYEZ: DEVELOPING NFC TECHNOLOGY TO ENABLE THE VISUALLY IMPAIRED TO SHOP INDEPENDENTLY

by

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Submitted in partial fulfilment of the requirements
for the degree of Master of Computer Science

at

Dalhousie University
Halifax, Nova Scotia
July 2014

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ABSTRACT

A large number of people throughout the world have visual impairments that make everyday tasks difficult, ultimately reducing independence and quality of life. VirtualEyez is a low cost system that uses a mobile phone app and NFC tags to allow visually impaired people to shop independently within grocery stores. Although this system is primarily designed for visually impaired people, anyone can interact with it to obtain indoor navigation services and product information from the tags. The overall objective of the VirtualEyez system is to improve the quality of life for visually impaired people by using NFC and smartphone technologies to support navigation and product identification. The prototype tested here was designed to check product availability, generate optimal directions to that product, and provide information about it upon arrival. The VirtualEyez system was developed using a Google Nexus 7 tablet with an Android 4.3 platform, NFC tags (NTAG 203 tags), and a small database containing two tables, one containing general product information and the other containing product location information. This thesis describes a study conducted in a mock grocery store, in which sighted, blind and visually impaired participants used the VirtualEyez system to navigate through the store and locate specific products. By measuring their performance in this task and interviewing them afterwards about their experience with the system, we illustrated the effectiveness and usability of VirtualEyez and established what improvements are needed in order to develop it in to a commonly used aid for visually impaired shoppers.

LIST OF ABBREVIATIONS USED

ADT   Android Development Tools

GPS   Global Positioning System

ISO/IEC   International Organization for Standardization/
                                        International Electro technical Commission

JVM   Java Virtual Machine

kps   Kilobits per second

LLCP   Logical Link Control Protocol

Load-modulating   The impact of load changes on the carrier field's amplitude
                                        of the initiator's. The initiator perceives these load changes
                                        as information that based on coils' size, the range from 4 to
                                        10 cm and data rates of 106, 212, and 424 kBit/sec

NFC   Near Field Communication

NDEF   NFC Data Exchange Format

NDEF payload   The application data carried within an NDEF record.

png   Portable Network Graphics

QR code   Quick Response Code

OTP   One-Time Programmable

RFID   Radio Frequency Identification

RF   Radio Frequency

RTD   Record Type Definition

SDK   Software development kit

Tag   Collective term used for NFC transponders of any type
                                        as well as QR codes

Type 2 Tag Platform   A legacy platform supporting a subset of a Technology
                                        (also called technology subset). Uses a particular subset of
                                        NFC—Type A technology including anti-collision.

CHAPTER 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 visual impaired (WHO, 2012). Visual impairment is increasing in prevalence all over the world over the last three decades, although 90% of visually impaired people live in developing countries (WHO, 2012). Nonetheless, 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 their eyesight, and the ubiquity 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" (Lighthouse International, 2013, para.1).

Most visually impaired people have difficulties not only with things like reading, but also with such basic daily activities 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 such tasks independently and without human assistance. Nonetheless, it is common for visually impaired people to turn over responsibility for personal finances, shopping and the like, and are often thought by sighted people to be unable and/or unwilling to accomplish such things 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 allow for a full life. Indeed, as Dan Rossi, 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" (as cited in Lanigan, Paulos, Williams, Narasimhan, 2006, p.2). Therefore, there is an urgent need to build a system that increases the independence of visual impaired and blind people, thus allowing for greater quality of life.

One of the most basic activities made challenging by visual impairment 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 is difficult and time consuming: visually impaired people have to listen to all the 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 (King, 2008). Some organizations also offer home delivery, but even when available it requires the customer to make a specific appointment and then wait for delivery. These alternatives limit personal autonomy and make independent shopping prohibitively difficult. As a result, blind and visually impaired people often avoid procuring these services at all, further disrupting quality of life. In order to purchase a product in person at the grocery store, blind people have to either ask a grocery employee for help or hire someone to assist them while buying their items (NFB, 2013). Not all grocery stores assign an employee to accompany a person with a vision loss around the store, and hiring an assistant is too expensive and offers no privacy. In short, the currently available solutions for these problems related to visual impairment are not satisfactory.

This research aims to address this issue through development 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 (the International Braille and Technology Center Staff, 2006). Although they are therefore limited to memorizing functions or relying on sighted assistance for many features, many visually impaired people own and use smart phones (the International Braille and Technology Center Staff, 2006). 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 (2006).

The system developed here, called VirtualEyez, aims to address the two main issues facing visually impaired grocery shoppers: navigating the store and locating items of interest. It does so by indicating the shortest route for customers to reach the product

being sought, thus making it potentially useful not just for the visually impaired but for all shoppers. The system also addresses product identification after the customers have reached their desired items.

The system is based on an android operating system, the Java program Eclipse, and NFC technology. NFC technology is presently being implemented in new generation devices, so it may become standard smartphone technology in the near future. Specifically, the VirtualEyez system uses android phones enabled with NFC technology with an SQLite database and NFC tags. Users will be able to record their selected items using a voice recognition service or by typing their selected items using a smart phone keyboard. The application will check the availability of the selected item and provide an audio/text message to inform the individual. The user will also receive a map to guide them through the store, accompanied by an audio message that provides direction commands for shoppers with vision loss. Thus, the navigation system suggests the shortest route for customers to reach their products. When the users reach their destination, the system also offers a product recognition service that uses an embossed NFC tag posted on each top shelf and an NFC reader on the smart phone to read product information and provide an audio message conveying that information. In providing this functionality, VirtualEyez makes it possible for visually impaired individuals to shop independently and, as a result, to take control of one important aspect of their daily lives.

The main objective of this thesis is to build a system that uses an NFC-capable smartphone and an indoor navigation system to guide shoppers with vision loss within the grocery store, to assist them in identifying target items and to provide information about those products via embedded NFC tags. This is a low cost, deployable system that does not require retailers to build entirely new systems. Crucially, it is easy to operate for people who have limited technological skills because they will be able to use their familiar mobile phone devices equipped with a simple user interface.

The main advantage of the VirtualEyez system is that the user interface is simple. It includes automatic activation of navigation subsystem using NFC features. Shoppers can

easily update their directions by touching the NFC tags distributed around the store. Users do not have to carry large or bulky technological devices in order to obtain the benefits of the VirtualEyez system. The cost of the indoor navigation system is low, as implementing passive tags is inexpensive. Response times are short due to the short amount of time required to transfer data from an NFC tag to a device and to generate an application's new path. Importantly, NFC tags can store accurate positions for the products, such that the tags are sufficient for the indoor navigation system.

The system should have the following properties:

- Guiding blind and visually impaired people inside the store
- Identifying the target products
- Providing product information
- Reducing the dependency on others' assistance
- Reducing the time spent shopping

By achieving these objectives, we can achieve the overall goal of minimizing the difficulties that blind people face when they buy their groceries. One of the most significant limitations for people with visual impairment is their inability to purchase their groceries in unfamiliar stores. Therefore, the essential motivation of our project is to help visually impaired people find their groceries quickly and easily. Our project will save them time by showing the location of the products that customers need while making them more independent. The VirtualEyez system will also inform the customers about the price and general product information. The system was developed using a Google Nexus 7 tablet with an Android 4.3 platform, NTAG203 tags, and a database containing a products table, which has 120 products, and a geometric table, containing all position points' coordinators in the floor plan of the grocery store.

This study will determine the advantages and weaknesses of the VirtualEyez system by collecting user feedback and opinions regarding the application and by testing it in a virtual grocery store created at the CNIB in Halifax. In doing so, this study will evaluate the effectiveness and the simplicity of the application. We will report qualitative and

quantitative results from user studies with five blind people, two visually impaired and two sighted people. The data resulting from these user studies will ultimately enhance the usability of our app's user interface. The results of this study will also indicate whether the application meets the needs of the visually impaired and if it will help the blind and visually impaired to shop independently.

The thesis begins, in Chapter 2, with an overview of existing indoor navigation and product identification systems, and also gives a brief introduction to NFC technology and Google Voice, Google's speech recognition service. In addition, Chapter 2 presents a brief overview of barriers faced by visually impaired people while shopping, and identifies the existing applications that attempt to eliminate these barriers. Chapter 3 describes the VirtualEyez framework for developing an NFC application that checks the availability of selected items, guides shoppers within a grocery store, and helps them identify their items. Chapter 4 addresses the implementation of the system. Chapter 5 presents the initial evaluation process that was used to evaluate the usability of the system. Chapter 6 presents the findings of our study and analyzes the application's performance. Finally, Chapter 7 presents conclusions regarding the functionality of the VirtualEyez system, and also discusses current limitations as well as possible avenues for future work.

CHAPTER 2: BACKGROUND AND LITERATURE REVIEW

2.1 Definitions of Near Field Communication (NFC)

NFC is a wireless technology formerly based on RFID that uses a frequency of 13.56 MHz, which is available around the world. It was developed by Sony and Philips in late 2002; currently, there are 140 NFC Forums and 130 countries participating in the development of NFC technology (Du, 2013). NFC and RFID carry the same features: both use interacting electromagnetic radio fields and are wireless connectivity technologies. In contrast to RFID, however, NFC is a short-range connection (4 cm) – although some NFC tags are capable of transmitting data over longer distances – mostly used in mobile phones. Furthermore, NFC technology only supports a one-to-one connection. Transponder data capacities range between 48 bytes and 9 kilobytes. There are various data rates supported by the NFC standard, including 106kbps, 212kbps, and 424kbps (NFC, 2014), and NFC tags can be rewritable, read-only or write-once. Each tag has a unique identifier (UID). Importantly, there are two types of communication modes used by NFC to exchange data:

1. In **active mode**, two NFC devices both produce a radio field while they communicate. Each device uses an amplitude shift keying (ASK) modulation scheme to modify its RF field in order to transmit data to another device. Each device in this mode generates an electromagnetic field, potentially leading to an RF field collision. To prevent collision, the sending device produces an RF field and, while listening, the receiving device turns off its RF field (März, 2011).

2. In **passive mode**, only the NFC-enabled device produces a radio field and begins the communication session; only the initiator from the mobile device emits the 13.56 MHz carrier field. The receiver (NFC tag) draws energy from the device and does not produce a carrier field. The initiator transmits information directly by modulating the existing radio field, and interacts with the target NFC tag through load-modulation. This mode enables NFC-capable devices to communicate with contactless smart cards (März, 2011).

2.1.1 NFC uses

Du (2013) reported that by 2014, more than 150 million mobile devices will be equipped with NFC service (p. 351). This trend suggests that users seek the easiest way to use smart phone functions. NFC has many benefits and potential uses in the application field that might drive various innovations by NFC. It is compatible with a variety of devices, providing a chance for unlimited future growth. At present, NFC is typically used for payment systems, personal identification and access control. It can also be used in ticketing services, where a mobile phone acts as a card or tag. In this situation the mobile phone is in card emulation mode. Any mobile phone that has ticketing or payment applications has to incorporate a secure element (SE) in order to eliminate attackers. In addition, NFC technology allows mobile phones to share data between two NFC devices using the peer-to-peer communication mode. For instance, users can share photos, documents, and messages by sending and receiving radio signals between NFC-capable devices. In the future, we will be able to use smartphones to provide our healthcare identification as well as to control our home appliances.

2.1.2 The components of an NFC tag
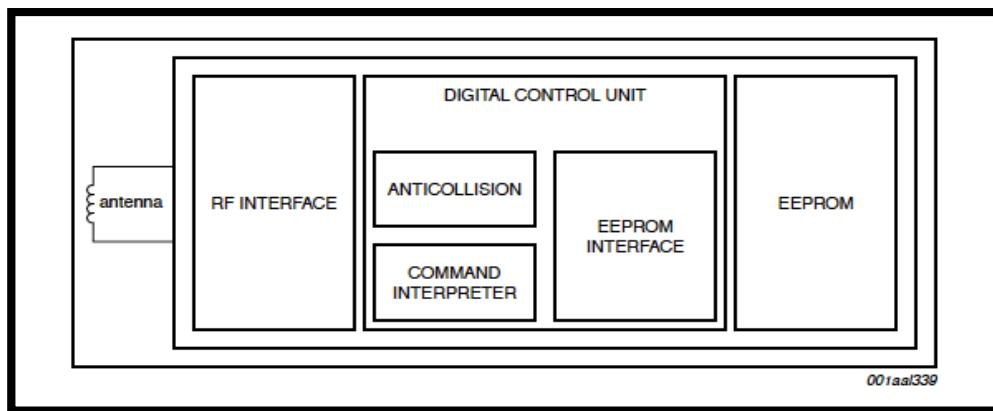
Figure 1. NFC block diagram

1. RF Interface (ISO/IEC 14443A)

NTAG203 allows contactless transmission of data and supplies energy so that there is no need for battery power. Because NTAG203 operates at a 13.56 MHZ frequency range, its operating distance is four centimeters or less. Each NFC tag has a serial number containing 7 bytes (cascade level 2 according to ISO/IEC 14443-3); this kind of NFC tag is characterized by high data integrity of 16-bit CRC and true anti-collision.

2. EEPROM

The total memory is 168 bytes, which is divided into 42 pages, each of which has 4 bytes. Users can read and write in 144 bytes of memory area, which is divided into 36 pages, each of which has 4 bytes. The first 64 bytes are reserved for the read-only locking function per page, 32 bits are reserved for a user definable One-Time Programmable (OTP) area, and 16 bits are used for the counter.

3. NFC Forum Tag 2 Type compliance

NTAG203 IC complies fully with the NFC Forum Tag 2 Type technical requirement (NFC Forum, 2007), and also enables the configurations of the NDEF data structure (NF Forum, 2006). The command interpreter NTAG21xF provides processes memory access instructions (2006).

4. Security

Each device has a unique 7-byte serial number to support anti-cloning. In its security area, the first 512 bits are used for the read-only locking function per page, 32 bits are used for a user-programmable OTP area, and the rest of the memory is occupied by read-only locking per block.

5. Cascaded UID

In order to prevent collisions while transferring data from NFC, the anti-collision function has a 7-byte serial number called a unique identifier, which is based on the IC individual. This serial number also supports cascade level 2 according to the ISO/IEC 14443-3 standard.

6. Anti-collision

By using a unique identifier, the anti-collision function is capable of operating more than one tag at the same time. This is because the anti-collision algorithm executes a specific transaction with a selected tag, and then performs the task perfectly by eliminating data corruption caused by other tags.

2.1.3 Operating modes of NFC technology

NFC devices support three types of operation modes, which are based on the ISO/IEC 18092 NFC IP-1 and ISO/IEC 14443 contactless smart card standards**:**

1. Reader/writer mode: data is exchanged between NFC devices and a tag. The device enabled with NFC is able to read NFC tag content (an NFC tag attached to a smart poster). An NFC device permits reading and action according to the content of the tag. In this mode, Record Type Definition (RTD) and NDEF data exchange format are used. Furthermore, the RF interface is compatible with the FeliCa schemes and the ISO 14443 standard.

2. Peer-to-peer mode compatible: data exchange between two NFC devices uses the Logical Link Protocol (LLCP), in which both devices perform the communication session. This mode enables users to share Bluetooth or Wi-Fi as well as exchange data, such as digital photos or documents. The peer-to-peer mode is based on the ISO/IEC 18092 standard.

3. Card emulation mode: In this mode, devices enabled with NFC operate as a traditional contactless smart card or tag, with external readers reading the contents embedded within NFC devices. This mode is used for specific applications, especially those using confidential data. For instance, payment applications interpret Visa card numbers as confidential data, such that the Visa number is written in the secure element of the smart phone and that confidential data is read via the external reader and then sent for further processing. By using NFC devices, this mode allows for various contactless

payments, such as mobile payment, ticketing access control, and ticketing applications, without altering the existing structure (NFC Forum, 2013).

2.1.4 How does NFC work?

1. The NFC reader produces a radio frequency (RF), which is sine wave signal at a frequency of 13.56 MHz, to transmit energy from the reader to the NFC tag as well as to retrieve the tag content.

2. Sine wave signals produce magnetic fluxes from which each NFC tag within the magnetic flux area obtains energy. Next, the NFC tag creates a counter frequency, changing the original sine wave frequency properties generated by the NFC reader.

3. The smartphone detects changes and thus knows that there is an NFC tag nearby.

4. The distance that data can be transferred between two devices or devices and tags is 4 cm or less, making this a close coupling system. One advantage of this short operating distance is that it eliminates the need for a power supply because, at such a short distance, the tag extracts a large amount of the signal processing energy from the magnetic field. Second, this short distance provides a high level of security (Braue, 2011). Figure 2 shows how an NFC tag interacts with an NFC-enabled device.
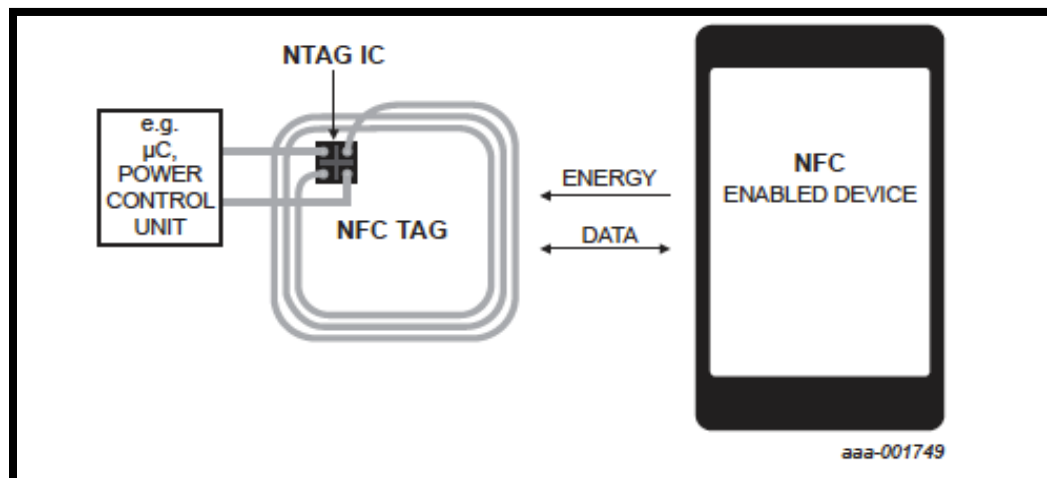
Figure 2. NFC tag interacting with device capable with NFC
(Adapted from NTAG203, 2011)

2.1.5 NFC Forum standards

1. The **NDEF format** is an NFC data format used to exchange data between NFC capable devices and tags. The NDEF message is lightweight, using 0's and 1's to compress payload contents for one or more applications into one NDEF message. Each NDEF message can contain one or more NDEF records. A common format for NDEF records is illustrated in Figure 3 below. In the next section, the individual record fields are described in detail.

2. The **Record Type Definition** document contains the definition of the record format or payload, as defined by the NFC forum. Possible RTD formats include URL, MIME, NFC Text, NFC URI, NFC Smart Poster, NFC Generic Control, and NFC Signature.

3. The link-level protocol **LLCP** was introduced by the NFC Forum to enhance the peer-to-peer mode. LLCP provides two-way connections, meaning that it supports sending and receiving of information between two NFC devices. LLCP allows exchange of data by two methods: 1) connection-oriented transfer, which requires data exchange acknowledgement; and, 2) connectionless transfer, which does not require data exchange acknowledgement.
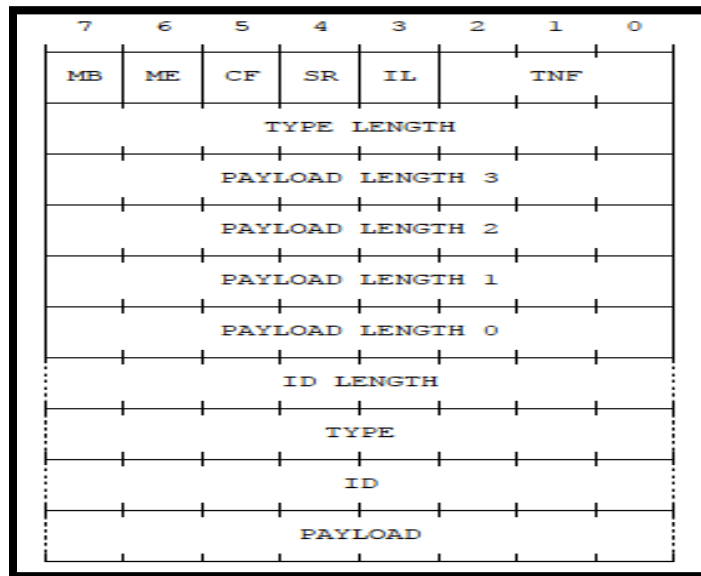
Figure 3. NDEF Record Layout (adopted from NFC Forum, 2014)

Data is exchanged through an NDEF message that might have more than one record. Each NDEF record consists of the payload data itself, organized as byte array and data fields describing the data.

2.1.6 The reasons for using NFC tags

There are various reasons for incorporating NFC technology into the VirtualEyez system. Users simply touch the NFC tag with a device enabled with NFC to begin the required service. An NFC device is able to read information stored in the tags and to write data into the memory of the tag, enabling users to obtain product information (price, expiry date, and ingredients) immediately by touching the tag. Moreover, by using NFC tags, we can build low cost indoor navigation systems using cheap passive tags. NFC technology also minimizes response time. The time required for transferring data from the NFC tag to the mobile device and the time required to generate the application's new path are both short. Importantly, NFC provides accurate position and orientation information. Location privacy of the user is guaranteed because NFC provides exclusive control over user location data. The critical reason that NFC is used in various fields is that it works in dirty environments (e.g., snow, water, dust and sand) and it does not demand a direct line of sight between the reader and tags.

2.2 Android accessibility features

The Android platform provides accessibility features in order to make phones easier to use for people with visual impairments.

2.2.1 Google Voice, speech recognition

Voice recognition software that transcribes speech into text, and the main function of Google's version is to record what the users say when they are nearby the mobile phone. After it offloads the recorded sound, it processes it to the cloud, where it interprets the speech and accurately produces matching text. Not only can this speech recognition system recognize any length of speech, but it can also recognize speech with an accent (Raux & Eskenazi, 2004; Google, 2013). It recognizes speech using artificial intelligence

(AI), and Google developers have stored a lot of speech words from numerous users in order to enhance the ability of this service to recognize words independent of accents and ambient noise levels.

We integrated into our app a Google Voice Search app, which is a recognizer app that is available for the Android operating system and that supports different languages. This app needs an Internet connection because the app processes the voice to the cloud and the voice recognition occurs on Google servers where it interprets the speech generated corresponding text. The voice recognition app contains a simple user interface that tells when a user can speak and when a user can stop talking. After that the app obtains the strings of the interpreted speech (Pavlov, 2013).

2.2.2 Android Text-to-Speech engine

Text-to-speech (TTS), or speech synthesis, is an engine for artificial speech production. TTS systems convert written words and files into spoken audio using synthetic voices. TTS service uses a complex system of linguistic rules and dictionaries in order to synthesize text into sound, and various implementations already exist.

A TTS system contains three main modules: linguistic, phonetic and acoustic. The first two steps in text-to-speech, comprising the linguistic module, involves inputting a text into the system and then converting the input text into a phonetic representation. The third step, representing the phonetic module, involves calculation of the speech parameters from the previous step. In the final step, comprising the acoustic module, synthetic speech is generated using the calculated parameters (Schröder, 2009). There are two main aspects of TTS systems: text analysis and generation of speech signals (Edgington et al., 1996), as illustrated in Figure 4. There are various resources for the input text, including word processor data, e-mail, text messages, and electronic documents. During the conversion of sound to text, the character string is preprocessed and analyzed into a string of phonemes with extra information regarding correct intonation, duration, rhythm, and stress; together, this information makes up the phonetic representation.

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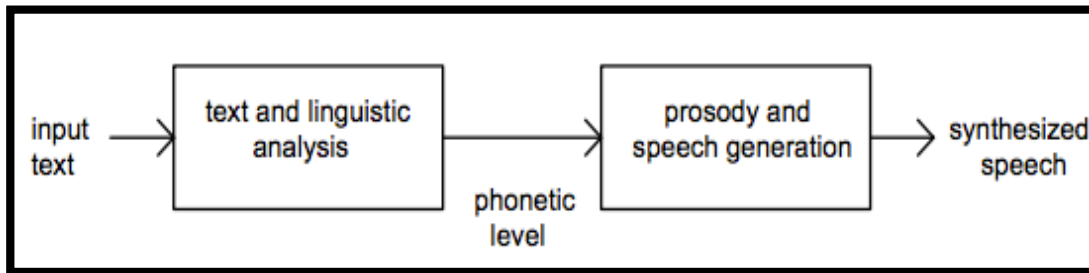
Figure 4. Simple text-to-speech synthesis procedure

We installed the TTS engine that is available in the Android platform and it supports different languages. Then we used the speak method to read the text on the screen aloud.

2.2.2.1 TTS features

The main objective of TTS is to enhance the functionality of user interfaces, including making the output of the application more accessible for blind users. The advantage of the TTS service is that it can be integrated with other systems of user input and output. Easy-to-learn and easy-to-use applications may also integrate this service (I 2Web Consortium, 2011).

2.2.3 The limitations addressed by VirtualEyez

The following section will detail the limitations faced by both sighted and visually impaired people that the system addressed.

2.2.3.1 indoor navigation system

One of the most basic shopping-related limitations for visually impaired people is the inability to navigate and orient in an unfamiliar grocery store without assistance. Visually impaired people find that navigating inside a building is more difficult than outdoors, where they can rely on guide dogs, white canes and landmarks. Since buildings are missing well-known landmarks, visually impaired people may find navigation risky and

hard to achieve without assistance, forcing most of them to resort to asking store assistants for help. Also, most existing indoor navigation systems are prohibitively expensive and therefore not an option for many visually impaired people (Hesch & Roumeliotis, 2007; Ivanov, 2010).

2.2.3.2 Item selection

Navigating the aisles is not the only difficulty facing visually impaired people while grocery shopping. Reading the food labels, expiry dates and price tags on grocery products also represent major challenges for people with visual disabilities. The most challenging task for blind and visually impaired people is identifying and distinguishing among different products (Brady, Morris, Zhong, White, & Bigham, 2013; Lanigan et al., 2006). Indeed, while most blind people can identify some types of food by touch, such as fruits and vegetables, it is really hard for them to identify items in cans and boxes (Lanigan et al., 2006). Clearly, it is nearly impossible for them to discriminate between containers that feel the same but that have different contents (Gill, 1995). This obstacle is a serious one, considering that a potentially hazardous product may be mistaken for something else (e.g., a glue stick being mistaken for lip balm). To get help with these issues at a store, a visually impaired person must wait for a store assistant to be available to help, potentially causing the individual to stay home or to plan his or her shopping trip around times that the store is expected to be empty (Lanigan et al., 2006).

2.2.3.3 Sighted people's limitations

Most people plan to buy their grocery items in a relatively short time. Unfortunately, they may spend a lot of time looking for a product of interest. Some people check the aisle sign several times to make sure they are in the correct section. Some of them ask for help from the store assistants. Thus it is not only visually impaired people that face challenges efficiently navigating grocery stores.

2.3 Existing systems assisting blind and visually impaired shoppers

The following sections provide an overview of the most notable existing technologies.

2.3.1 Indoor navigation system

Navigation indoors is a very challenging task due to the lack of or low GPS signal inside buildings. Nevertheless, enhanced smartphone capabilities have provided opportunities to solve this problem, and there are several indoor navigation systems currently available on the market to help sighted and visually impaired people easily identify the target destination.

There are various systems that determine locations using tags, such as NFC tags, RFID tags, QR codes, or infrared beacons. These tags can be developed to determine location using an active system, in which the user's device reads passive tags to compute the location. For example, ISIK University of Istanbul proposed research that uses NFC tags to connect location information (Ozdenizci, Ok, Coskun, &Aydin, 2011). Ozdenizci et al. (2011) designed a mobile application named NFC Internal, which is an indoor navigation system that uses NFC. The purpose of the application is to eliminate current indoor navigation problems, such as the high cost of hardware. NFC Internal allows for the easy transfer of data for indoor navigation by touching tags spread around a building.

2.3.2 Assistive shopping systems

Many assistive shopping systems have been developed to address the problem of blind and visually impaired people grocery shopping independently. One existing assistive grocery shopping system is Robo-Cart, a robotic shopping assistant developed at Utah State University (Kulyukin & Gharpure, 2006). It guides users in a grocery store using a Pioneer 2DX robot embedded with a laser range finder and RFID reader to navigate the shopper to the location of the products. The shopper has to follow line patterns on the floor with the scanner's camera to navigate within a grocery store, and use a hand-held barcode scanner to identify a product. The main advantage of the Robo-Cart system is

that installing lines on the floor is a reasonable, reliable, and inexpensive alternative to using RFID tags or laser range finding and odometry (such as SLAM), which are expensive and lack privacy. Furthermore, SLAM's reliability has decreased, especially in open spaces and in aisles with lots of glass surfaces (e.g., refrigeration aisles), because glass deflects laser signals (Kulyukin & Gharpure, 2006; Kulyukin, Gharpure, & Pentico, 2007).

Previous studies by Ali and Nordin (2009) focused on developing an assistive navigational system that recognizes the surrounding environments of blind people using a camera embedded in their cane. The purpose of attaching a camera to the cane is to capture all frontal views, including the particular features and structures of what is captured. The application sends captured images to a database for comparison to images already stored in the database in search of matching features. This system also uses Dijkstra's shortest path algorithm to find the shortest path to reach the destination from the current location. While testing the system, blind people asked for multiple training sessions to learn to use the system, and a view-matching process was carried out to guide them to their destination. The main drawbacks of their system are the long response time, owing to the linear process of finding the shortest path, and the required retrofitting of an existing system, which necessitates retraining the user along with updates to the application.

In 2008, Chumkamon, Tuvaphanthaphiphat, and Keeratiwintakorn proposed an indoor navigation system using RFID technology implanted into a footpath to be readable via an RFID reader embedded in a cane. It uses GPRS networks to communicate between the navigation device and routing server. This system helps blind people to find the shortest route from their current location to their destination. In addition, it automatically recalculates a new path for the users who get lost. The main disadvantages of this proposal are long response time to user requests and voice delay, which is due to a server communication delay via the GPRS cellular network (due to the cold start cycle of a GPRS modem).

Ivanov (2010) developed a system combining mobile terminals and a Java program with access to RFID tags. It offers a map of the rooms, including 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. It also offers voice-enabled navigation. This system has several advantages. 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. Each tag has information about the location of all the reference points inside the room. This system also allows blind users to rely on the white cane in order to overcome any obstacles in their way. It supports audio navigation and requires a web server. It interacts with the users' movements in a reasonable amount of time. One of the major disadvantages in this system is the high price of RFID tags, which is not affordable compared with the average income of the blind.

Similarly, López-de-Ipiña, Lorido & López (2011) proposed a system called BlindShopping, which is a low-cost mobile system. (A similar system was created by Upadhyaya (2013)). Aiming to allow independent supermarket shopping by visually impaired people, BlindShoping uses an RFID reader embedded on the tip of a white cane to guide users at a supermarket using the RFID tags attached to the supermarket floor. It also uses embossed QR codes posted on product shelves and an Android phone camera, enabling users to recognize and identify products of interest. For system configuration, BlindShoping requires a web-based management component that produces barcode tags for the shelf (López-de-Ipiña et al., 2011). The main advantages of this system are that a supermarket does not have to go through costly and time-consuming installation and maintenance processes. Moreover, users who use the BlindShopping system do not need to carry additional new 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, the blind user must send the image of a product to a remote database on the web to identify it, which requires both a significant amount of time and internet access, which may in turn make this option too costly for some visually impaired individuals.

Nicholson, Kulyukin, and Coster (2009) have proposed a system called ShopTalk to help people with visual impairments find the correct shelf in the grocery store. ShopTalk comes with a small CamelBak backpack containing a computation device, a numeric keypad to enter data, a barcode scanner, and a USB hub in order to connect these various components. The system output is a verbal path and search directions produced from a map, which is based on the barcodes positions. The map joins the store entrance, aisle entrances, and customer service location and is stored in a computational device. The overall objective of ShopTalk is to allow blind customers to find the correct aisle and shelf, which is based on the barcodes. A key limitation of this system is that it does not address the problem of product identification, so the customer may be aided in getting to the correct location but could still fail to select the correct product.

Nicholson et al. (2011) have addressed the product identification issue, proposing the ShopMobile system be used to address this particular limitation of ShopTalk. ShopMobile 1 (Kulyukin & Kutiyanawala, 2010) has a camera equipped with a mobile phone connected wirelessly to a barcode reader. The mobile phone has a screen reader and a screen magnifier to enable customers to scan Modified Plessey (MSI) barcodes on shelves, so the customer can reach the exact location of target products. In addition, the system uses UPC barcodes posted on products to allow customers to verify that they have selected the correct product.

Building on that, Kulyukin and Kutiyanawala developed ShopMobile 2, which transmits voice and image data from users' phones to the remote system, allowing them to get help from remote sighted guides. Using smartphones to enable visually impaired people to shop independently, it contains three software modules: an eyes-free barcode scanner to enable users to scan UPC product barcodes; an optical character recognition (OCR) engine to enable users to read barcode labels and nutrition information on each product; and TeleShop, a teleassistance module. ("Teleassistance" refers to a wide range of technologies used to enable people with no vision to transmit video and voice records over wireless connections to remote computers to obtain voice assistance.) The TeleShop module provides a backup for the barcode scanner and OCR engine in case they fail or

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break down. ShopMobile 2 has been successfully tested in a workshop study. The major drawback of this system is that it does not support transmitting video streaming or voice recordings in real-time, so users will need a lot of time to buy their target products.

Another interesting assisted shopping solution is iCare, which was developed at Arizona State University. Customers use an RFID reader attached to a glove to find the products' location from a server via Wi-Fi. Each product also carries RFID tags, and the customer can read any product name by touching the product with the glove (Krishna, Balasubramanian, Krishnan, & Hedgpeth, 2008). Similarly, Trinetra (Lanigan, Paulos, Williams, Rossi, & Narasimhan, 2007) 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. That means the user is responsible to find 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.

GroZi, another assistive grocery shopping system, was developed at UCSD by Belongie, Miller, Foo, Kokawa, Wurzbach, and Mueller (2009). The system uses a custom device called a MoZi box, which consists of a camera and a haptic feedback mechanism. When the user points the MoZi box at the products, the MoZi box collects the products' images and compares these images with those stored in database in order to find the location of the target products and guide users towards them. Because of the mechanism used, MoZi, like other systems, takes a lot of time to identify the selected product.

There have been some recent examples of NFC-associated systems being used or tested in different fields. Karpischek, Michahelles, and Resatsch's (2009) Mobile Sales

Assistant (MSA) has been successfully implemented in a clothing department store. This system combines NFC and the Electronic Product Code (EPC) in order to optimize and speed up the sales process in retail stores by permitting customers to check the availability and supply information of products immediately at the point of sale. Given these benefits, MSA has the potential to increase customer satisfaction as well as sales. Another noteworthy example is a system called HearMe to support visually impaired and older users in identifying medication and finding important product information (e.g., dosage) by transforming information from the package (encoded in NFC tags) into speech (Harjumaa, Isomursu, Muuraiskangas, & Konttila, 2011) . This app is designed to eliminate the need for nurses and family members to remind the patient of scheduled medication. Similarly, The French supermarket chain, Casino, is conducting a pilot study with blind shoppers to understand the possibility of 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 (McLean, 2011). The main focus of Casino project is to assist blind and visually impaired customers identify the products. The most valuable aspect of this project is that it enables shoppers to obtain general information about products. However, the fact that the customers have to touch products in the supermarket randomly until they find their desired products – because there is no indoor navigation system – means that the process of acquiring information for the correct product may be quite lengthy.

2.3.3 The limitations of assistive shopping systems

Most current indoor navigation systems require the use of technological infrastructure that would necessitate changes to the structure of the building. These systems, which serve a variety of functions (e.g., identifying obstacles in the path of the blind user and recording what is in front of the user), are inconvenient for daily tasks because they are heavy and complex (Ross & Blasch, 2002; Willis & Helal, 2005; Ganz et al., 2012; Ali & Nordin, 2009; Chumkamon, Tuvaphanthaphiphat, & Keeratiwintakorn, 2008) and often require robot assistance (Krishna, Panchanathan, Hedgpeth, Juillard, Balasubramanian, & Krishnan, 2008), which is not a reasonable option for the majority of users. Because of

the prohibitive cost of most existing systems, few have actually been implemented in a real environment. Furthermore, some assistive systems exhibit long response times that greatly slow the shopping experience. In addition, using only an identification system without support from an indoor navigation system means a lot of time to assist customers finding the item of interest. For example, if the customer is looking for black tea, he has to touch all the items in his way until he finds it. This necessitates a lot of effort from the customers and, in some case, from store assistants. Using NFC technology for both navigation and identification systems offers the possibility of eliminating the factors that limit the success of existing systems. Such a combined system promises a solution that is cost-effective and easy to implement.

2.3.4 The limitations of RFID, Wi-Fi, and barcode technology

The limitations of RFID-based navigation over NFC-based navigation include long response times that greatly slow the shopping experience. When RFID tags are attached to items such as liquid in metal cans, the radio field waves refract and reflect the waves during communication. Using RFID technology in an environment where glass is present the waves will be reflected by this glass, thus affecting the outcome of the system. In addition, tagging each product with an RFID tag is quite expensive for a retailer, and the cost of the RFID reader (glove) is quite expensive for users. The high price of RFID tags makes them unaffordable for the blind based on their average income. Another issue is that RFID does not meet users' demands for trust and privacy since the readers are accessible to anyone. These issues are difficult to address due to the technical problems they present.

There are several limitations of using Wi-Fi in indoor navigation systems. The accuracy of Wi-Fi positioning is unreliable and inconsistent and depends on the Wi-Fi Access Point (AP) database quality and the signal reception. In addition, the density of the APs in the server database differs dramatically in different situations. If the current area is covered by very light APs, the subsequent positioning accuracy will be poor. Wi-Fi

signals also suffer from reflection and blockage due to obstructions, and disturbance from nearby electrical appliances can lead to weak signal reception (Mohammadi, 2011; Huang, 2013).

Both NFC and barcode technologies are relatively cheap and easy to use. However, barcodes require line-of-sight and precision, which is difficult for blind users. Since barcodes posted on products and shelves give no tactile information blind users must spend a lot of time trying to read them. Traditional barcodes store a minimal amount of information (McCathie, 2004) so scanning them will not inform users much. Another limitation of barcodes is their environment. Because barcodes must be in view they are subject to damage by stresses associated with movement across the supply chain or weather.

2.4 The novelty of the VirtualEyez system

The VirtualEyez system is a novel solution that uses an android app equipped with an NFC reader in combination with NFC tags attached to store shelves in order to identify the items and to guide the users within a grocery store. This will help shoppers to find their items in a short time without asking for assistance. The novelty of our application is that it uses an android device that is NFC-capable, providing for an easy-to-use interface supported by voice messages that simplifies navigation within a grocery store and identifies products' for people with impaired vision. This system also combines the best aspects of existing systems in a way that promises to enhance the quality of life of sighted, blind and visually impaired people.

The VirtualEyez system will provide an indoor navigation system and link it with an identification system using NFC tags deployed in each shelf in the grocery store and implanted at the entrance/exit. The specific characteristics that distinguish VirtualEyez from existing systems are: 1) the shopper is not required to carry any gadgets other than his android phone; 2) the deployment of NFC tags in the store and the cost of maintenance is very low because of the use of passive NFC tags; and, 3) it combines an

indoor navigation system and identification system so that the blind person will not only reach the correct section but also be able to select the correct item.

2.5 Summary

This chapter defined NFC technology and discussed the two categories of communication modes used to exchange data via NFC (active and passive modes). This chapter also highlighted the main uses of NFC technology and the main reasons for choosing NFC technology for the VirtualEyez system, in part by providing an overview of existing assistive shopping grocery systems and discussing their advantages and disadvantages.

CHAPTER 3: STUDY FRAMEWORK

3.1 VirtualEyez platform

In this chapter the proposed system framework is defined. The system components are explained using the flowchart and the system's functions. The algorithm that is used for indoor navigation is introduced as is a layout meant for assisting people with vision disabilities.
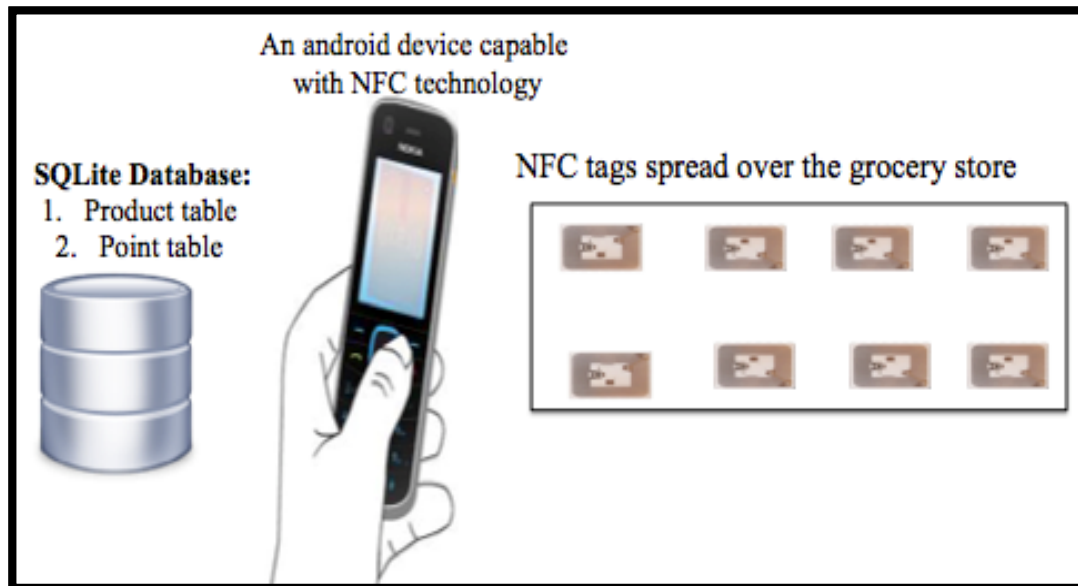

Figure 5. VirtualEyez components

The architecture of the VirtualEyez system, depicted in Figure 5, consists of the three major components:

1. **Passive NFC tags** deployed on every top shelf in the grocery store, 100 cm apart from each other, and at the entrance/exit (Figure 6).
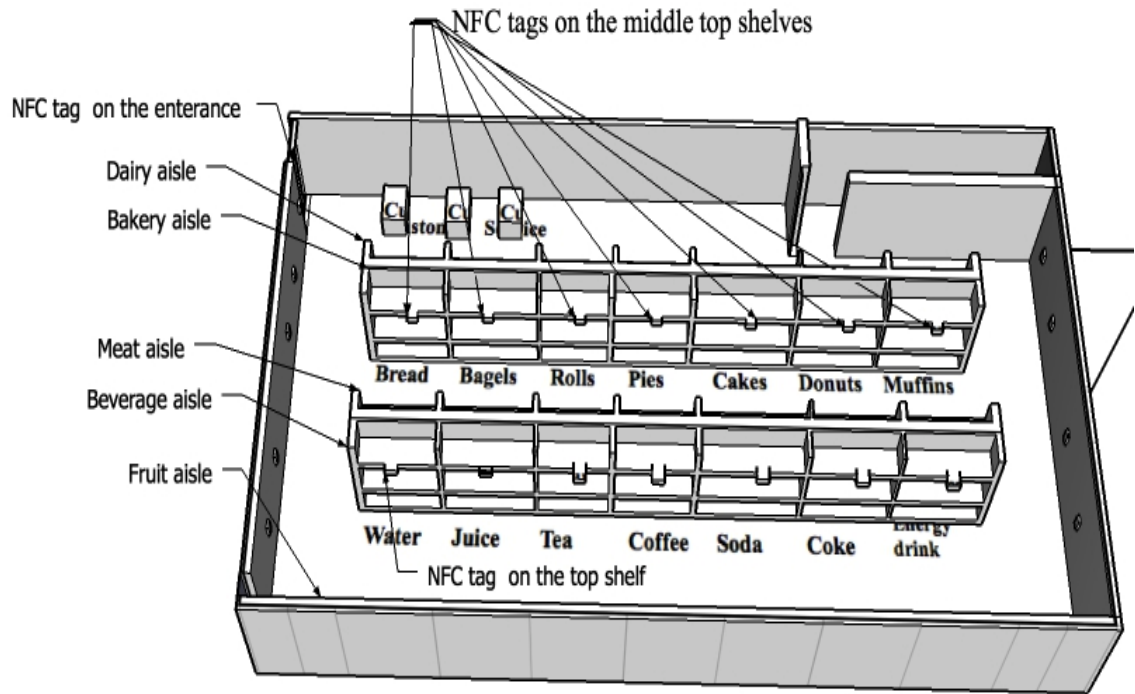
Figure 6. Locations of NFC tags

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.

2. **NFC-capable Android device** as an NFC reader.

3. **SQLite database** storing the building 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 containing 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. That means 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.

3.1.1 Assumptions

The VirtualEyez system was designed based on the following assumptions:

▪ A virtual store in the CNIB center would consist of six aisles, including a customer service aisle, a dairy products aisle, a bakery aisle, a meat aisle, a fruit aisle and a beverage aisle. Each aisle would have seven sections, each with particular types of products, and each section has three shelves, representing varieties of particular products. For example, the dairy aisle's milk section contains whole milk on the top shelf, skim milk on the middle shelf, and chocolate milk on the bottom shelf.

▪ The virtual store in 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 the 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.

▪ The users would know the shape of NFC tags and where they could find them in the store.

3.1.2 Inputting and checking the availability of the desired product

This task is achieved by carrying out four sequential steps (Figure 7), as follows:

1. Enabling customers to input their item
2. Sending the inserted product to the database

3. Checking the availability of the chosen item

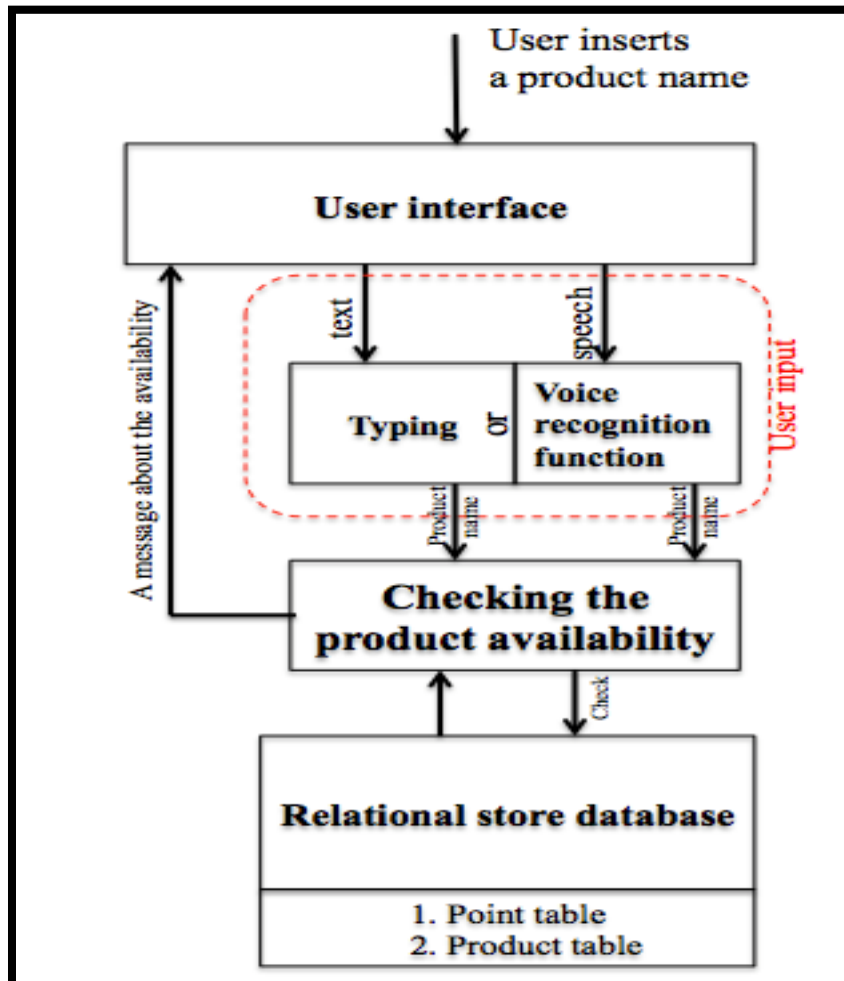4. Retrieving an alert message about the availability

Figure 7. Checking the availability of the desired product

Each step is critical to checking availability, and the steps are interdependent. After the shopper inputs his desired item, the application will perform the remaining three steps immediately. These four steps will be explained in detail in the following subsections.

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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 as described in section 2.2.1, the app will convert the voice of the shopper to text.

The second option is that the customers type their selected items using 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. If customers choose to type rather than say the product name, they must press the "send" button after hearing the product name from the talkback service that is available as an integrated accessibility feature on the Android operating system, so as to be sure that they have inputted the correct product name. We will describe this feature in the next chapter.

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" in order to inform the customer of the availability of his item. 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.

3.1.3 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 also can 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:
1. Scanning an NFC tag
2. Retrieving the location of the chosen item
3. Applying the routing algorithm
4. Representing visual or audible map

Some of these steps rely on the input value (product name) provided by the checking the availability function. For example, the routing algorithm takes the product position as one input for the algorithm. As a result, those functions are associated with each other, and, as such, shoppers cannot skip some steps and still gain the benefit of the system. Figure 8 illustrates how the indoor navigation system function works, and how it relies on the previous function in order to provide the shopper with the best route to his item.
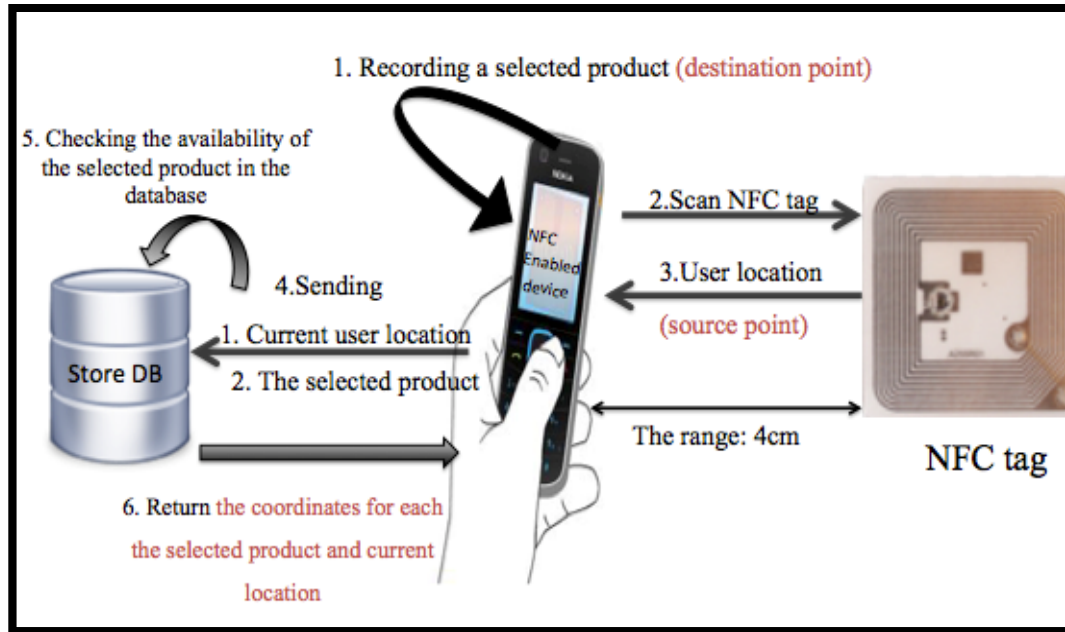
Figure 8. Indoor navigation system using NFC tags

The VirtualEyez application has the ability to do the following: read the NFC tag ID and send it to the grocery store database; receive the reply from the store database; and display the reply to the shopper as a text/sound message and visual/audio map (as shown in Figure 8).

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 or destination 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.

3.1.3.1 Using Dijkstra's algorithm

Dijkstra's algorithm was founded by computer scientist Edsger Dijkstra in 1956 and published in 1959. It is a graph search algorithm that finds the shortest path in a graph with a single source point and one or more destination points (e.g., finding the shortest route between cities). This algorithm is commonly used in a variety of different applications, such as network routing protocols, maps, robot navigation, texture mapping, urban traffic planning, optimal pipelining of VLSI chip, and subroutine in advanced algorithms. The algorithm works by processing a single node at a time. It starts from the source node (current location). Inside the loop, the algorithm selects a vertex that has the lowest cost from the source vertex. This vertex has been marked as visited node and has not yet been optimized. This process is repeated until all vertices are optimized. Once the algorithm reaches the destination, the optimized cost can be found out and the path can be deduced by traversing it in reverse order (Ahuja, Magnanti, Orlin, 1993; Dijkstra's algorithm in Java, 2010).

3.1.3.2 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 to the destination. For example, if the user is in the entrance of the store 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. As described below, VirtualEyez aids all of these populations by providing multiple forms of guidance.

There are some distinct challenges to building an indoor navigation system. Android and iOS supports developers with libraries for outdoor navigation systems, and mobile device platforms provide navigation techniques using cell networks, Wi-Fi or GPS. They also support the implantation of a map in custom applications in order to visualize location information. A map is the best way to visualize the coordinates of locations, and there are several services provided for outdoor maps, such as Google Maps, OpenStreetMap (iOS Technology Overview, 2012; Open Street Map, 2012). Nevertheless, there are limitations to indoor map solutions. If developers need to implant indoor maps in their applications, they have to create a floor plan of their test location to visualize coordinates on a map, which is complicated by the difficulty of finding floor plans that precisely portray measurements and layout.

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, such 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 9, the grocery store map has six aisles and seven sections in each aisle, so that there are seven nodes in each aisle.

Figure 9. Grocery store map

The user interface of the indoor map system is intuitive, facilitating 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 10 shows that After applying dijkstra algorithm, the On Draw function will receive all the points 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 points coordinates from the source node to destination.
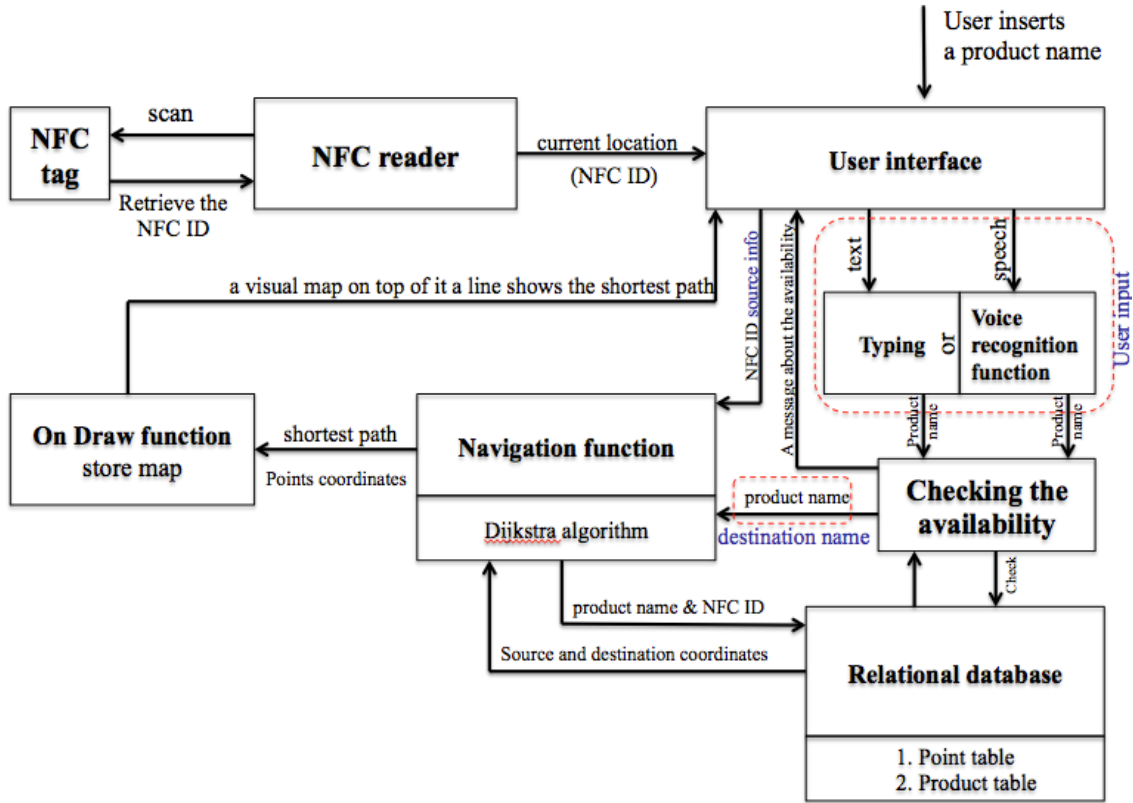
Figure 10. Indoor navigation system generates a visual map

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 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 (as described in section 2.2.2).
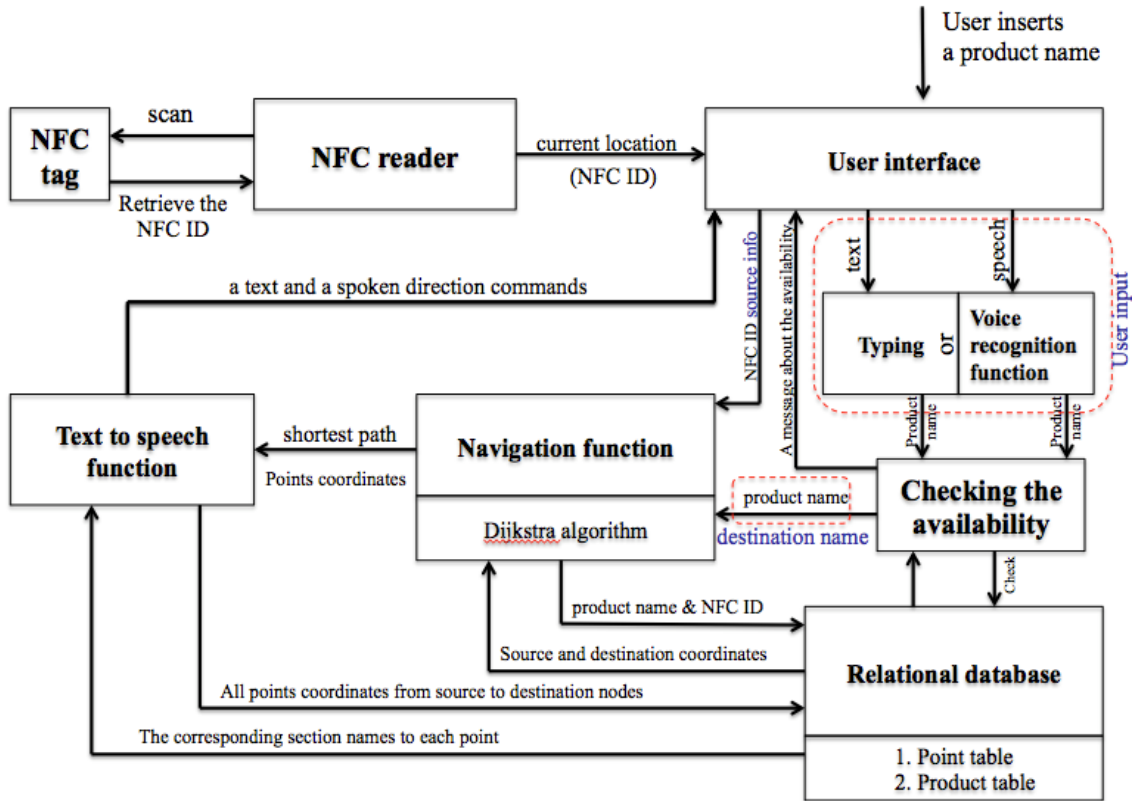
Figure 11. Indoor navigation system generates an audible map

Figure 11 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 points' 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 coordinates. After that, TTS sends the direction commands to the user interface as both text and voice.
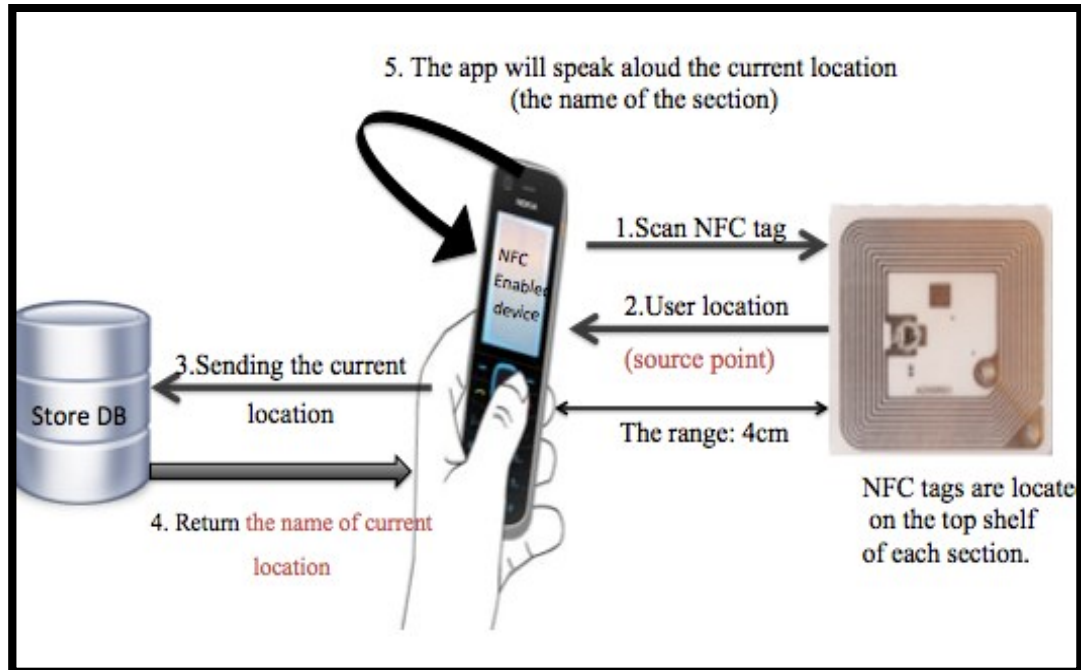
Figure 12. Recognizing the current location by using NFC tags

The audio map also has the capability of informing the blind or visually impaired shopper of their exact location at any point, which is of great value considering the limited capacity to acquire such information from landmarks. In order to know his exact location, he has to tap the NFC tag nearby in order to read the unique ID for the NFC tag, 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 (as shown in Figure 10). This is explained in greater detail in Chapter 4.

3.1.4 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, in particular, have selected the correct item.
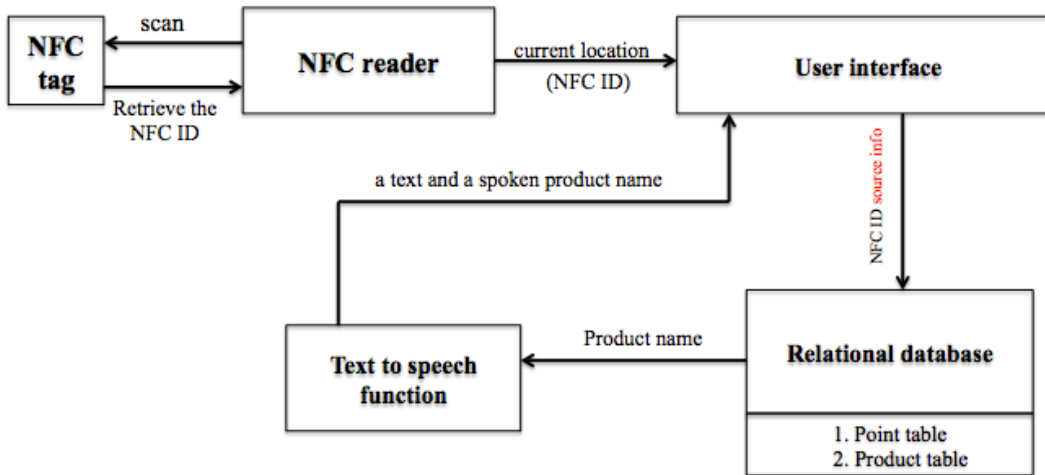
Figure 13. Product identification function

Figure 13 shows that when the user taps the NFC tag, the application will immediately read aloud the product name in order to inform him/her of the section name. It also aims to identify the product's name and to access 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 nutritional information is obtained from Health Canada website (Health Canada, 2008). For example, if the shopper presses the "description" button, the application will say, "The price is 5$". If shoppers need more information about their desired product, the application will also say things like, "The total fat is 12% and the cholesterol is 8%. It contains no Vitamin A. One cup of whole milk provides 150 calories, 8 g of fat, 12 g of carbohydrates and 8 g of protein. Five grams of the total fat content are saturated fat, while 11 g of carbohydrate come from sugar. This food is a good source of Vitamin D, Riboflavin, Vitamin B12, Calcium and Phosphorus" (Health Canada, 2008, p.1). 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.

In the following subsections, we discuss the VirtualEyez operating system and its procedures.

3.1.5 VirtualEyez system flowchart
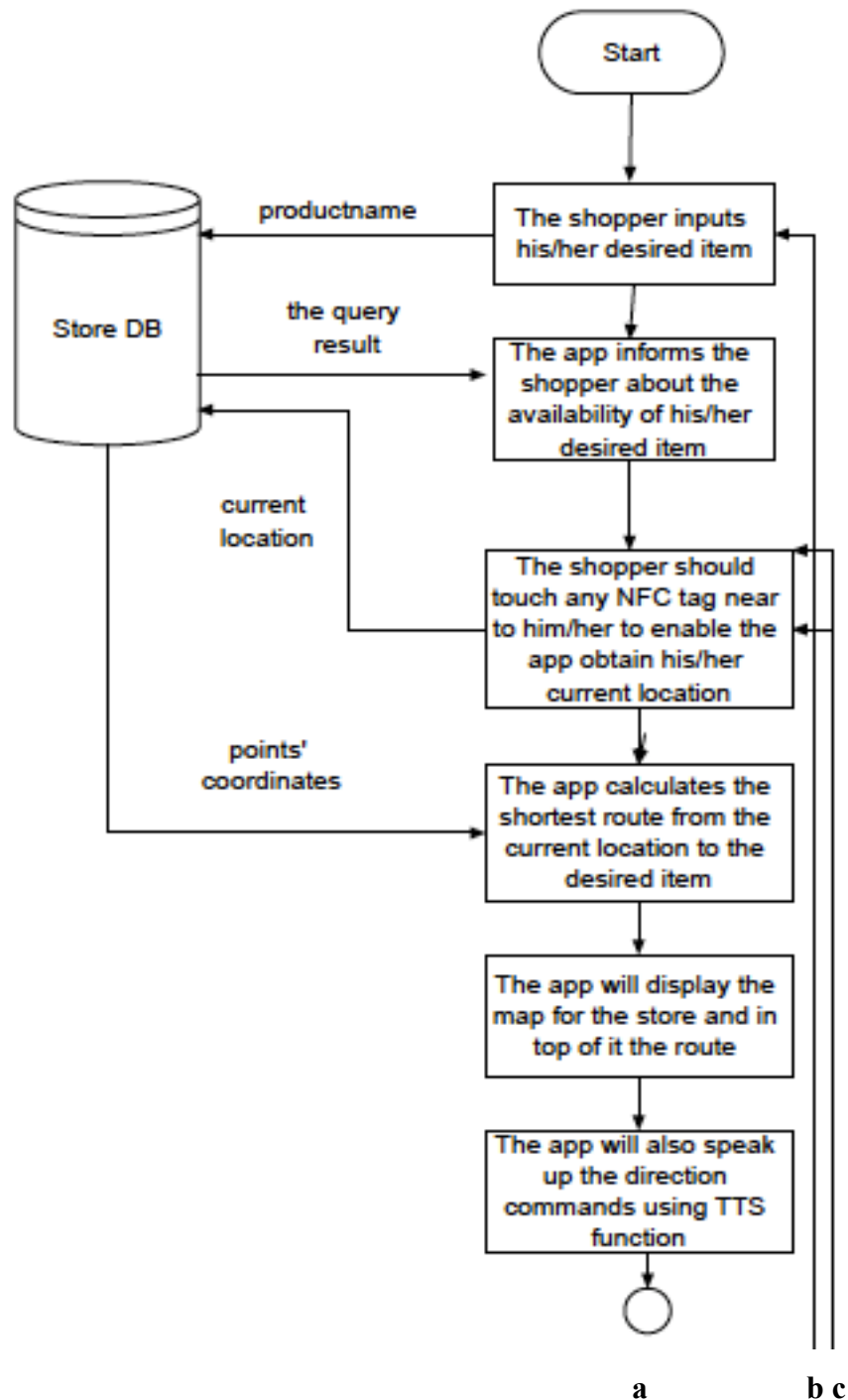
Figure 14. VirtualEyez system flowchart (1.a)

a   b c
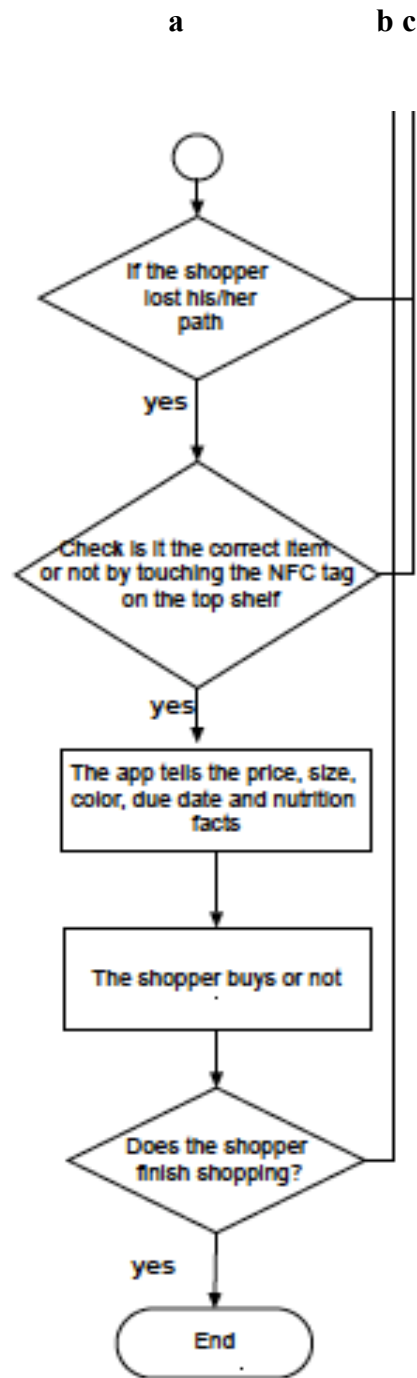
Figure 15. VirtualEyez system flowchart (1.b)

The VirtualEyez flowchart explains the sequential steps and how these steps relate to each other (as shown in Figures 11 and 12).

3.2 Summary

In this chapter, we discussed the proposed framework for the VirtualEyez system including the four fundamental functions of the VirtualEyez system including recording a selected item and checking its availability, indoor navigation system, and product identification. This chapter also presented the flowchart of the VirtualEyez system. We also explained the Dijkstra algorithm, which used to build the indoor navigation system and then we discussed how we presented the navigation system outcome to the end user using visual and audible maps.

CHAPTER 4: IMPLEMENTATION

This chapter presents an overview of the key technologies being used within the VirtualEyez system. Implementation and testing of the VirtualEyez system took place in the CNIB center, Halifax, Canada. In the following sections, we discuss the various experimental tools, the experimental services, and the experimental model for the application.

4.1 Experimental Tools

In this section, we describe the experimental tools used in the VirtualEyez application. The ways in which these tools were used is discussed in the 'Experimental Model' section.

4.1.1 Android OS

The Android smartphone operating system is open source for developers. This operating system is an ideal environment for VirtualEyez for several reasons. For one, Android is very popular among developers because it offers a high availability of documentation and shared knowledge. Most Android applications are developed in the Java language. Android applications can use many libraries, which were originally developed for the JVM, and Android applications operate within the Dalvik VM, which is a technology similar to the JVM. In addition, the large number of Android users means that new applications can quickly get used by many people, resulting in abundant feedback (Vodička, 2011). Moreover, most recent Android devices are NFC-capable, such that they are able to read stored data in NFC between two devices or between devices and NFC tags.

4.1.2 Tablet capable with NFC

The VirtualEyez application was tested on a Google Nexus 7 tablet running Android 4.3 (Jelly Bean). The processor of Google Nexus 7 tablet is a 1.5 GHz Qualcomm Snapdragon S4, and the size of internal memory is 16GB (Nexus, 2013). We used a

Google 7 tablet as our NFC reader to install the VirtualEyez application to read the content of NFC tags.

4.1.3 NFC tag

NTAG203 (F) tags (NT2H0301G0DUD or NT2H0301F0DTx) are used in the VirtualEyez system. It operates at a 13.56 MHZ frequency range that requires four centimeters distance or less to be readable. It is supported by ISO/IEC 14443-3 (Type A) and ISO/IEC 14443-2 (Type A) air interface protocol standard. NTAG203 is mainly designed for NFC Forum NDEF-compliant Type 2 Tag in order to develop various types of applications, such as advertisement, smart poster, connection handover, Bluetooth simple combining, Wi-Fi Protected set-up, call request, send email, launch map, set an alarm, SMS, and device authentication and others.

Figure 16. NTAG203 (F) tag

We used several NFC tags spread over the grocery store (on the entrance/exist and on each top shelf of each section, see Figure 16) in order to get the coordination of each location in the store for navigation and product identification purposes. Each tag has a unique ID used to identify the matched data in the store database with regard to both geometry and product details.

Table 1. Short naming convention (for easier product identification)

(NTAG203, 2011)

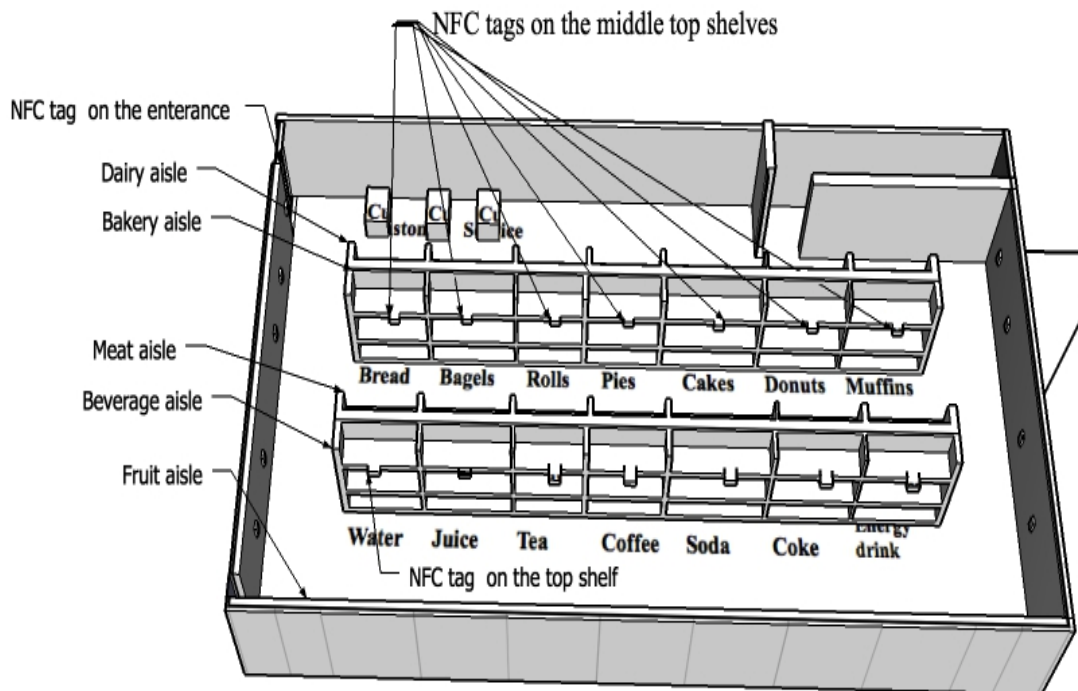| Family name	Description
NTAG	NTAG NXP NFC tag product family name
2	Platform indicator
0	Generation number (starting from 0)
3	Code number for memory size (0: < 64 bytes, 1: 64-96 bytes; 2: 96-128 bytes; 3: 128-256 bytes)
F	Delivery option: If stated, it is a HWSON8 package with Field Detection pin

Figure 17. NFC tags Locations

4.1.4 Eclipse IDE

This is an Integrated Development Environment (IDE) involving a workspace and a plug-in system for the development environment. Java language is used to write Eclipse IDE,

so it provides numerous functions involving Java editing with validation, incremental compilation, cross-referencing, code assist and an XML Editor (Eclipse, 2010).

4.1.5 Android SDK

Android SDK allows developers to build projects in the Android environment by providing the necessary API libraries and essential tools for building, testing, and debugging. It is also used to export either signed or unsigned Android application package ".apk" files to distribute applications. The Android SDK also provides an emulator and source code for debugging sample applications. Those applications are written using the Java language and executed on Dalvik. The virtual machine executes on a Linux kernel (Get the Android SDK, 2013).

4.1.6 ADT Plugin

Eclipse IDE has increased its capabilities by adding a new plugin, Android Development Tools (ADT), that enables programmers to build Android applications. In particular, the plugin allows programmers to create new Android projects, add packages, and create user interfaces using custom XML editors. Eclipse with ADT represents a big improvement in developing Android applications.

4.1.7 SQLite3 database

SQLite is a software library. This library has several key features:

1. It is **a self-contained,** meaning that SQLite does not need full support from either the operating system or the external libraries. This makes it ideal for smart phone use because it eliminates the need for modifications while running the application.

2. It is **serverless**, meaning developers can perform read and write processes directly on the database files on disk – SQLite does not ask for intermediary server process. This differs from other SQL database engines, that require a separate server process. In order to enable applications to access the database, there is a need to connect with the server

using an interprocess communication (typically TCP/IP). This protocol will send requests to the server and receive results from the database.

3. It is **zero-configuration**, meaning that developers do not need to install SQLite when they do not plan to use it because Android applications work well without it and developers will not be requested to run the "setup," nor will server process need to be started, stopped, or configured. In addition, SQLite does not require an administrator in order to build a new database or assign access permissions. SQLite does not use configuration files and does not require any action for recovering after power failure or system crash. There is also no need to do anything to inform the system that SQLite is running.

4. SQLite is a **transactional database**, such that any modifications or queries from the SQLite database are atomic, consistent, isolated, and durable. Because SQLite has serializable transactions, SQLite responds to system crashes and power failures in a consistent and durable way (SQLite, 2013). SQLite database provides various methods, such as open(), insert(), update(), close()(SQLite, 2013).

For the VirtualEyez system, we created a simple database featuring 120 products for our mock-grocery store. The main features of the store database are product information and geometry information. The grocery store database has two main tables. The product table contains product ID, product name, product price, product description, product aisle, product coordinators, and point ID (Figure 18). The product information (nutrition facts) were obtained from the Health Canada website (Health Canada, 2008). The point table, concerned with map information, contains point ID, point name, point coordinates, and the coordinates of the surrounding points (Figure 19).

Figure 18. Product table

Figure 19. Point table

4.1.8 SQLite Database browser

SQLite Database Browser is a graphic user interface (GUI) editor for SQLite databases. The main objective of this interface is to enable both developers and end users to create, compact, define, modify, delete, browse and edit database files using a group of spreadsheets as an interface. Using an SQLite database interface does not require learning complicated SQL instructions (Tabuleiro, 2014). The SQLite Database browser runs in different platforms and provides several functions for users including: creating, defining and deleting indexes, browsing, editing, adding, searching and deleting records, and importing and exporting records as text or tables.

4.1.9 TEXT Wrangler

TEXT Wrangler is a free text editor with an intelligent and easy-to-use interface, created by Bare Bones. It provides high performance that allowed users to edit, search and manipulate text easily. Furthermore, it offers various powerful features including search and replace functions between several files, syntax coloring for source code languages, code folding, and open and save functions. It also supports AppleScript and Mac OS X Unix scripting (Bare Bones, 2013). We used this application to write and edit and modify the VirtualEyez application code.

4.1.10 NXP TagWriter

This standard application is used for writing on NFC tags. This application is able to store various types of data including contacts, bookmarks, geo location, Bluetooth Handover, SMS, Mail, and text messages. NXP TagWriter also stores data to diverse items containing NFC-enabled electronics, such as posters, business cards, and watches. Once data has been stored, the application allows reading and viewing of the programmed data, with options to launch applications automatically based on the contained data. The NXP TagWriter has an intuitive interface and supports different functions like Bluetooth pairing, application launching, tag writing, and NFC editor. This app also provides the ability to convert QR codes into NFC data type. In addition, it can view the contents of an

NFC tag, as well as import/export and share NFC data sets. This application has the ability to back up an NFC tag's contents before writing it, and can also erase the contents of an NFC tag, write-protect an NFC tag, and write multiple NFC tags in sequence by increasing counter value when writing NFC data sets. It completely supports the NFC Forum Type 1 Tag, Type 2 Tag, Type 3 Tag and Type 4 Tag. It also supports different types of NFC like MIFARE Ultralight, MIFARE Classic, MIFARE DESFire, and ICODE SLI. In the VirtualEyez application, we use NXP TagWriter to store the NFC ID for each shelf in the NFC tags. This application enables developers to choose the type of data to be written on the NFC tag, such as URL or plain text.

4.1.11 NFC Tag Info

This application provides general information about the NFC tag that is being read. The general information includes the NFC tag type, size, and space available, as well as the type of data being written on the tag.

4.4.12 Microsoft Excel

This electronic spreadsheet program is used to store, organize and process huge collections of data. It is most commonly used to store commercial data for processing and using different functions, including basic mathematical operations (e.g., sums, averages, etc.). In addition, Excel can be used for graphing or charting specific data to aid users in visualizing data trends. It is also used to draw diagrams and flowcharts. In VirtualEyez, we used Excel to draw a map of the grocery store. Each row in the spreadsheet represents an aisle, and users can change the size of the aisles by adjusting the width and height of the columns and rows. We then used the "print screen" function to save the map as an image with the extension ".png," which is the only image format accepted by Eclipse.

4.2 Experimental services

4.2.1 Wireless Connection

We used the wireless service at the CNIB center to make a connection between the tablet

and the Google engine.

4.2.2 TalkBack service

This is an application designed under Google's Android Accessibility Service and provided as a pre-installed screen reader service on the Android platform. The main purpose of this application is to assist blind and visually impaired users by describing the results of actions (e.g., opening an application) and events (e.g. notifications) through spoken feedback. It provides voice messages for what they are trying to do with their smartphone by telling the users what they have touched and/or selected. In addition, the application can also read aloud the user movements on his/her mobile phone to allow the user navigate through menus, pages and other services (Nuñal, 2012; Google, 2013). To enable TalkBack application, users can go to *Settings > Accessibility* and enable the TalkBack service. Google developers update the TalkBack application regularly (Nuñal, 2012).
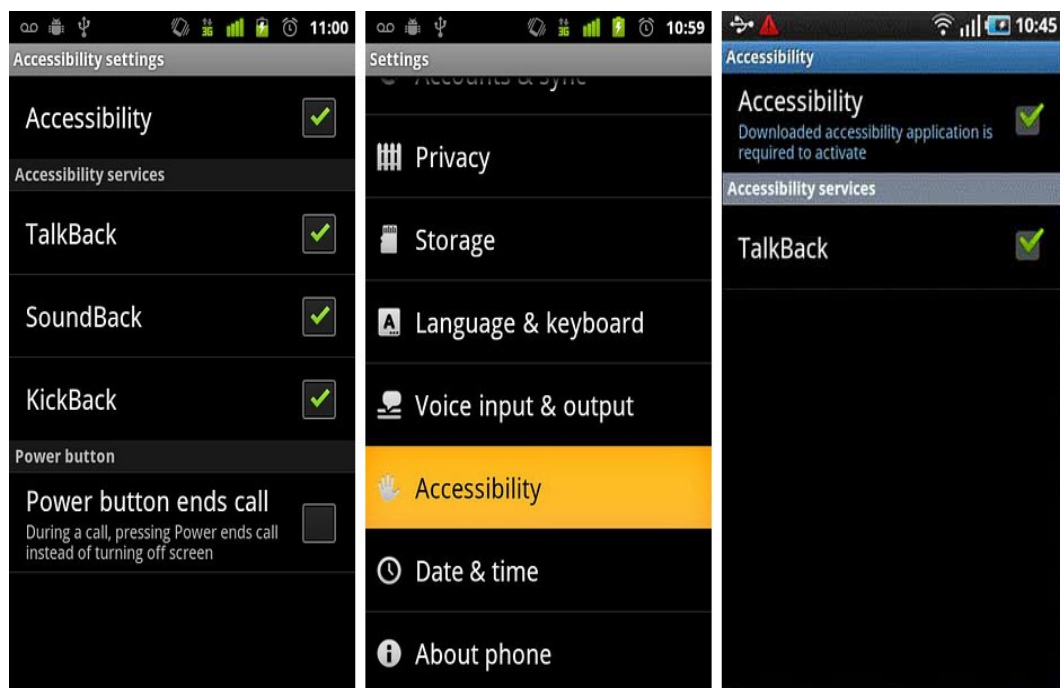
Figure 20. TalkBack service

We used TalkBack service in the VirtualEyez application in order to assist blind people and visually impaired people in navigating through our application from one activity to another, and in identifying which button they need to press to accomplish a specific task. For instance, when a blind user employing the TalkBack service presses a button, the service will speak aloud the name of the button. If the button is what the user was looking for, he can double click on the button in order to activate the function of this button. If the button is not what she was looking for, she can touch the application screen once for commands that will help her find the target button.

4.3 input and output guidelines for people with vision disabilities

The "iOS Human Interface Guidelines", which outline design principles for mobile devices for people with visual impairment, were used while creating the interface. Based on these guidelines we ensured that the interface had large buttons with high contrast font and based on the recommendations from "Designing for Screen Reader Compatibility" we added in a magnifier that enlarges the text size on the screen to assist visually impaired people. We also added a TalkBack service to read aloud the content of the screen to blind users (Russell-Minda, Jutai, & Strong, 2006; iOS Human Interface Guidelines, 2014; Designing for Screen Reader Compatibility, 2014).

4.4 Experimental model

In this section, we describe the implementation of the VirtualEyez system to guide shoppers within a grocery store as well as to assist them in identifying their selected items. We will describe the interfaces of VirtualEyez, including those for recording a customer's desired item, checking for an existing product in a store, retrieving a map and direction commands, guiding a customer within a store by providing a short route, identifying a selected product, and providing general product information including nutrition facts, expiry date and price.

4.4.1 VirtualEyez application interface

The application will be installed in the shoppers' android devices, as shown in Figure 20.
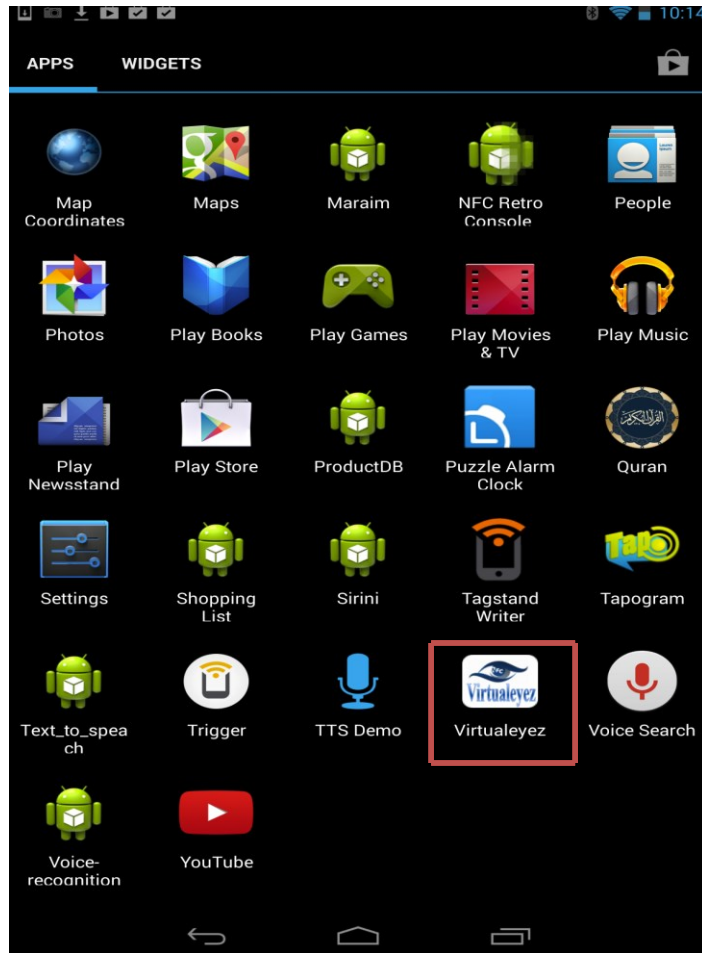
Figure 21. VirtualEyez application icon on the customer's android device

The application has three sequential views (as shown in Figure 21), each with a particular function. The value stored in each view transfers to the next one, such that each view depends on the preceding one.

(a)   **(b)**   **(c)**
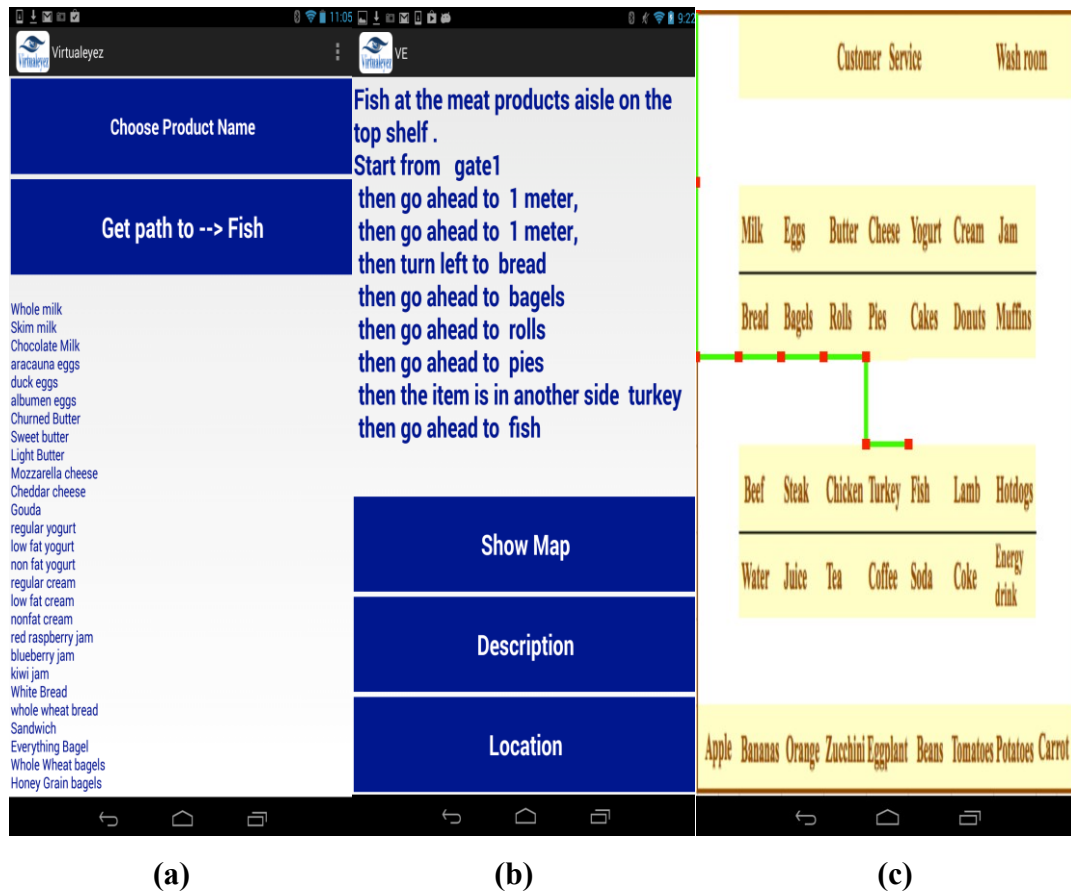
Figure 22. VirtualEyez interfaces

4.4.2 Recording or typing the chosen item and checking the availability

The VirtualEyez application interface also enables the customers to record their selected item. Visually impaired people have to use the accessibility service TalkBack, which is provided in each android system, to navigate within VirtualEyez application. Clicking on the "Choose product" button in the VirtualEyez application interface (Figure 22) brings the user to the recording screen (Figure 23), which runs the speech recognition service from Google, enabling customers to record the name of a desired item. The application also allows customers to type their selected item using the keyboard (see Figure 24).

53
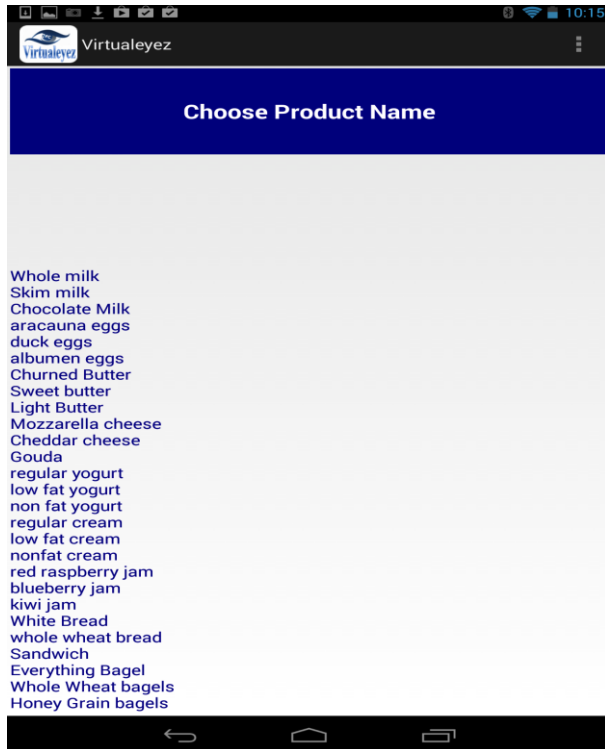
Figure 23. "Choose Product" button
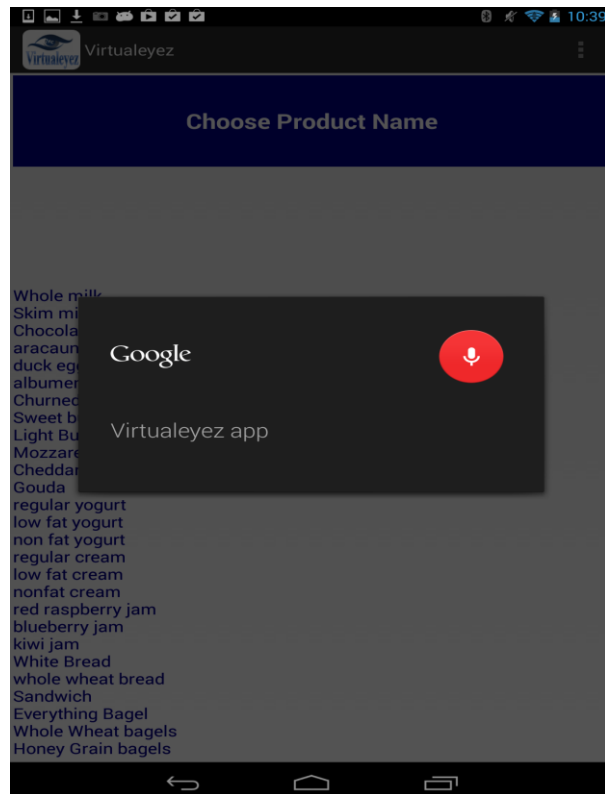
Figure 24. Voice recognition interface
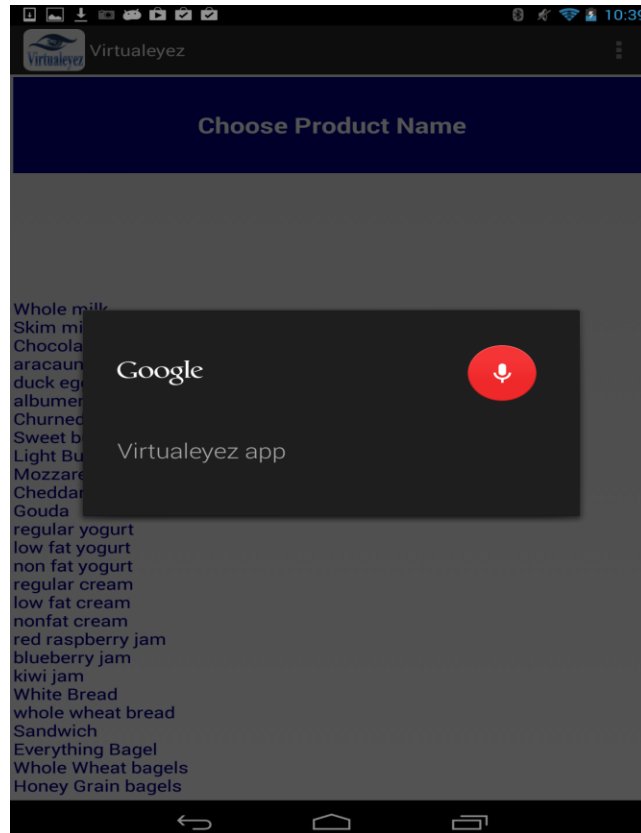
Figure 25. Typing chosen item

In response, the VirtualEyez application will retrieve an alert message to inform the customer of the selected item's availability (Figures 25 and 26). If there is a product in the store database matching the name of the product recorded by the shopper, the application will return a message to that effect: "The product is available." Likewise, the message if there is no matching product is "The product is not available."

Figure 26. The desired item is not available

Figure 27. The desired item is available

If the selected item is available in the grocery store, the indoor navigation phase will start. The targeted item location information will be downloaded to the mobile phone from the store database when the shoppers record their items.

4.4.3 Indoor navigation system

As mentioned earlier, the indoor navigation system is used to guide shoppers inside the store. We embedded NFC tags in each top shelf and in the entrance/exit. Text is written on NFC tags using Tag Writer in order to store the point IDs of store map coordinates data in the NFC tags. The users can use their mobile phone to scan any NFC tag. The targeted item location information will be downloaded to the mobile phone from the store database when the shoppers record their desired items. Based on the location of selected item, the application specifies a customer route using Dijkstra's algorithm. By clicking on the "get path to selected item" button (see Figure 27) in the VirtualEyez application interface, the user proceeds to the path screen.

Figure 28. "Get Path" button

4.4.3.1 Guiding a customer within a store by providing a short route

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 query sent to the database to find the shortest path is: *dijkstra (source ,target).*

In the above query, source is the starting point (current location) and target is the end point (the desired item location). The database executes the above query by generating an array, which contains a shortest route calculation between given two points (source and target). 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 is sent to a function to overlay it on top of the map image (Figure 28).
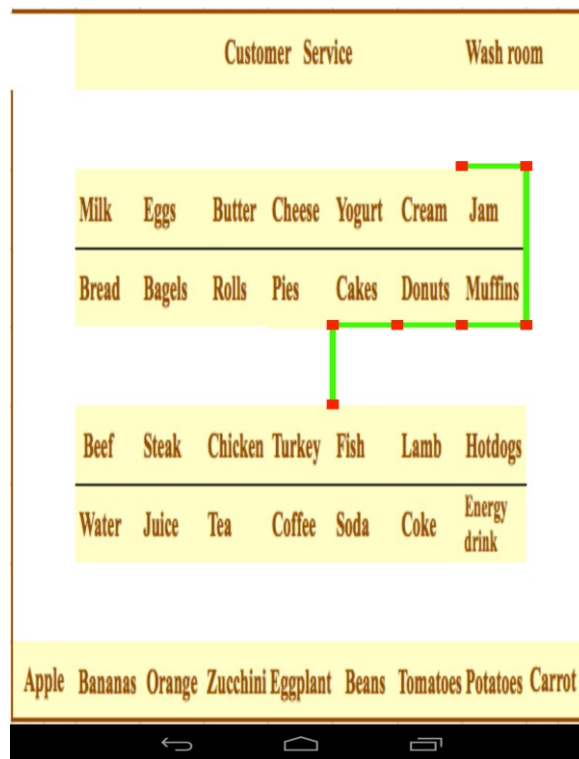
Figure 29. Shortest path on grocery store map

4.4.3.2 Grocery store map

In section 3.1.3.2, we pointed out the importance of maps to show the users their route from sources to destinations. The default situation is showing the route from the entrance to the selected product. For example, if the shopper wants to buy fish, he will obtain a path from Gate1 to the desired item (Figure 30). If the customer was near the jam section, he can touch the tag on the top shelf of the jam section. Then the customer will receive a visual/audio map, as shown in Figure 31.

(a)   (b)   (c)

Figure 30. An example of the default path

Figure 31. If the customer starts from jam section to fish

When the customer reaches his selected item, he should touch the NFC tag on the top shelf to confirm that he has reached the correct location. At that time, he will receive the visual/audio maps, as shown in Figure 31.
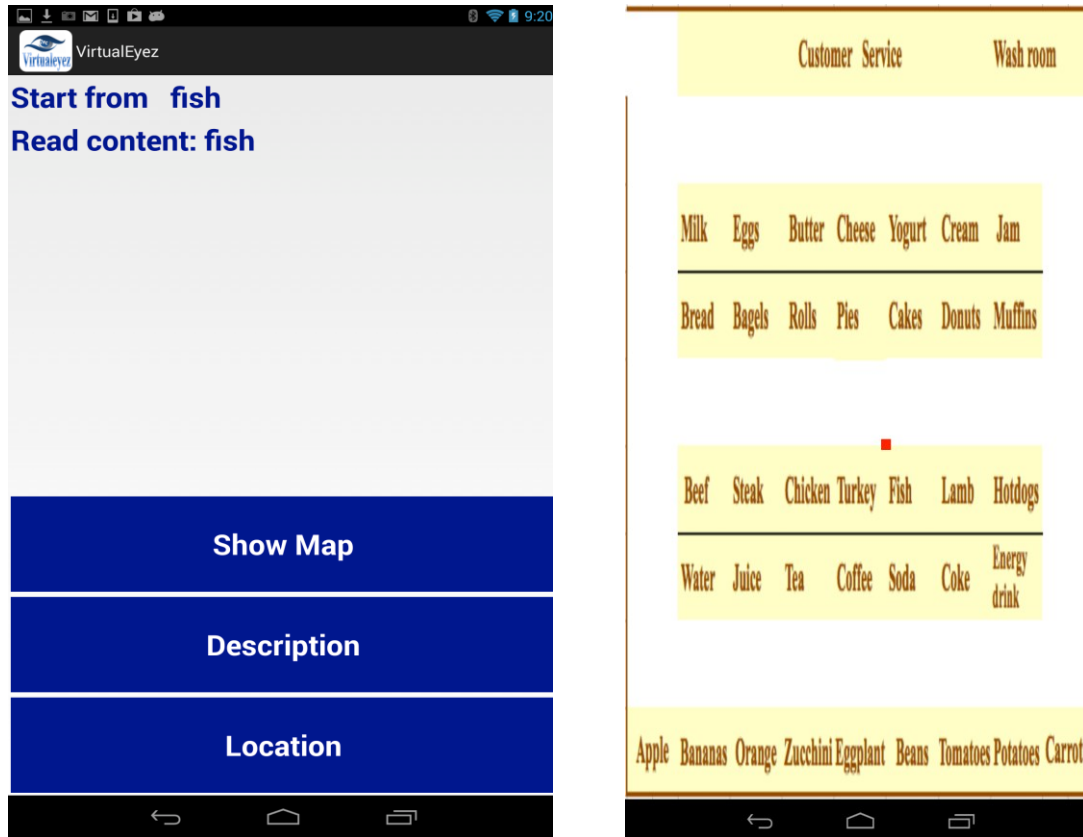
Figure 32. When the customer reaches to his selected item

4.4.3.3 Identify the exact location of the product

The exact location of each product is stored in the database, meaning that the customer will be informed about which shelf holds their selected item. For example, the shopper will receive a message stating that, "the low fat blueberry muffins are in the bakery aisle on the top shelf." The path screen also displays a text message containing the direction commands from the current location to the desired product. It tells the customer the name of the aisle that has the selected product and also shows the actual location of the desired item, such as top, middle or bottom shelf (Figure 32). Then, using the TTS service, the application will read the location aloud for the shopper, informing him or her of the product's precise location.
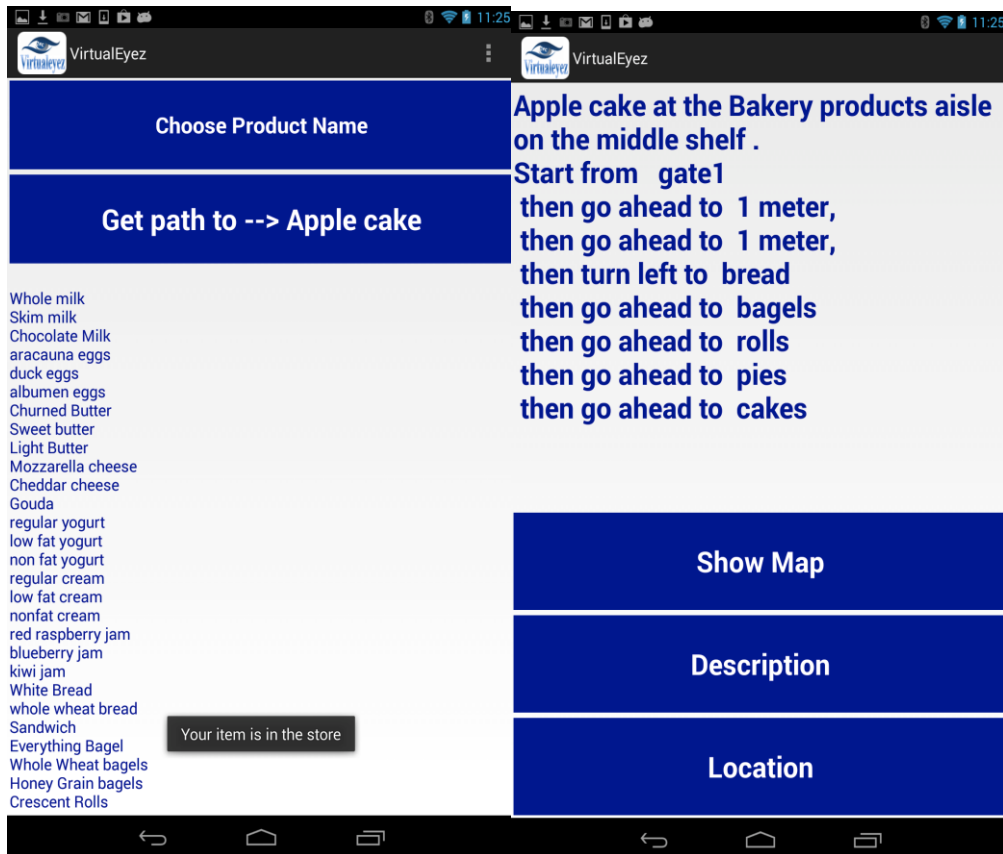
Figure 33. Direction commands as a text message

In case the customer forgets the directions commands, there is a "Location" button at the bottom of the screen, which the customer can press in order to hear the direction commands again (Figure 33). Thus, blind people are not forced to rely on memorizing the directions the first time they hear them.

For people who prefer to visualize the directions, the customer can press the "show map" button, which leads to an interface that has the grocery store map with their planned route (Figure 34). Thus, VirtualEyez provides direction instructions in three different ways: text, audio, and visual. As a result, the application is easy to use and of benefit to both sighted and visually impaired people.
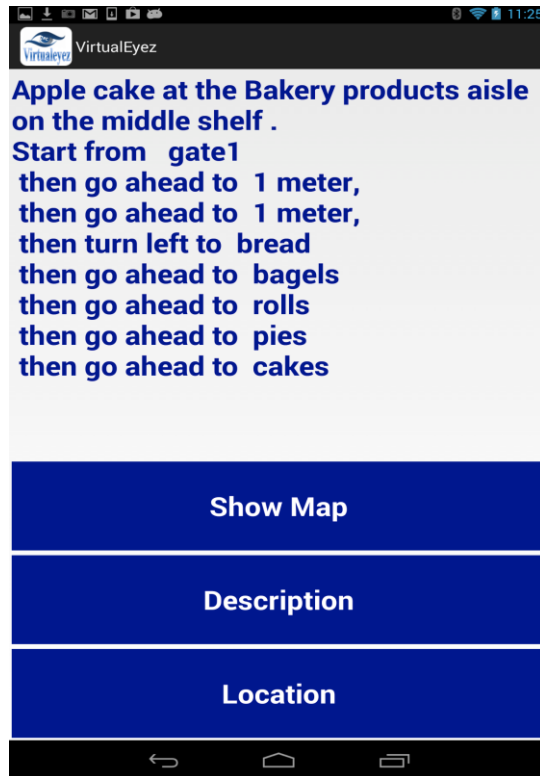
Figure 34. "Location" button

Figure 35. The path from the entrance to the Apple cake

If the shopper loses his path while walking in the store, he can simply touch any NFC tag along his way and the application will immediately update the route (Figures 35 and 36).
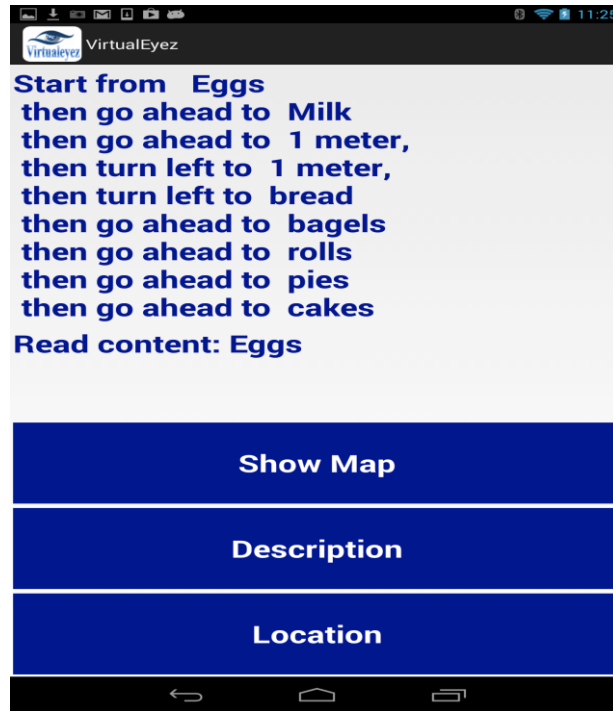
Figure 36. The direction commands from the eggs' section to the Apple cake
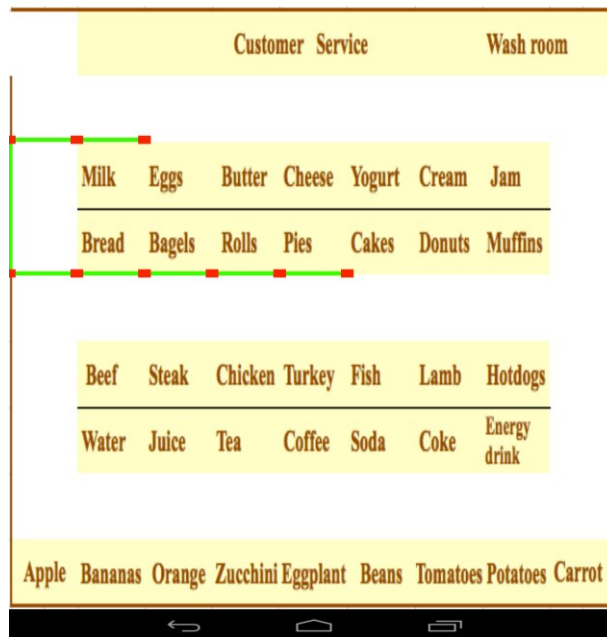
Figure 37. The path from the eggs' section to the apple cake

4.4.4 Product Identification

As mentioned earlier, product identification is used to help the visually impaired shopper identify their selected items by way of a voice message when the shopper reaches the selected items. The shopper can make sure that they take the correct item by touching the NFC tag at the top shelf (Figures 37 and 38).

Figure 38. The path from the cheese' section to the Fish
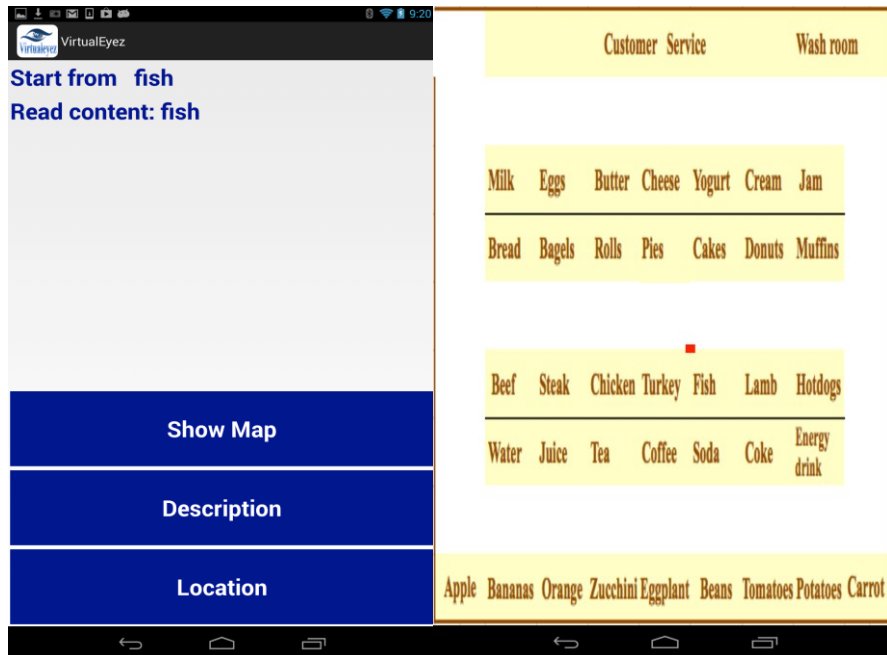
Figure 39. When the customer reaches his selected item (Fish)

The application also allows the customer to obtain general information (e.g., product name, price, ingredients, nutrition facts and expiration date) about selected items including nutrition facts, price and expiry date. Customer can press the description button in order to obtain such information about the selected item (Figure 40).
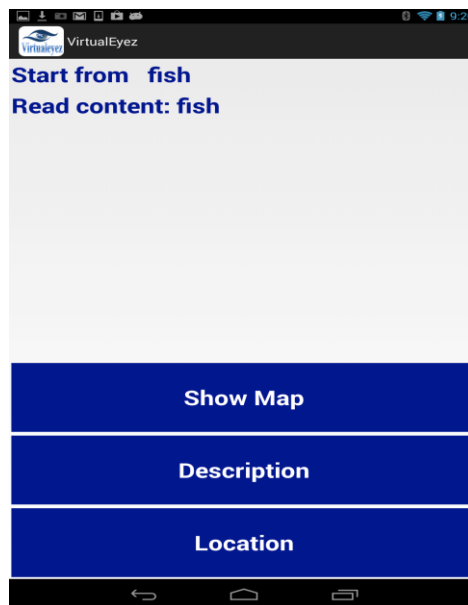
Figure 40. Description button

4.5 Summary

This chapter discussed the VirtualEyez application's proof of concept, which was implemented and tested in the CNIB center at Halifax. We first explained the experimental tools and services that were used in the VirtualEyez application and then demonstrated the experimental model that was used to build the application. In addition, we showed some examples of how the VirtualEyez system can be employed to located items in the grocery store. In this chapter, we also demonstrated the function of each button in the application.

In the following chapter, we discuss the evaluation of the VirtualEyez system usability and effectiveness, as well as the evaluation methods that were used.

CHAPTER 5: METHODOLOGY

This chapter describes the initial evaluation process of the VirtualEyez system to obtain users' feedback and initial impressions while using the app. It also attempts to obtain the users' suggestions to enhance the system. Specifically, the study was designed to evaluate the success of four tasks related to the application's ability to aid navigation in a grocery store: (1) to check an item's availability, (2) to guide the shopper through the supermarket via visual/audio maps, and (3) to identify the item and provide information about it.

To accomplish this evaluation, we set up a mock grocery store with 4 aisles in the Canadian National Institute for the Blind office in Halifax, Nova Scotia (Figure 41). Several products were set on the shelves to make the shopping experience realistic. The participants were asked to buy four products, which were located on different shelves, one product on the top shelf, one product on the bottom shelf, and two products on a middle shelf.

1. **Eggs**-bottom shelf
2. **Low fat plain yogurt** -middle shelf
3. **Fish**-top shelf
4. **Black tea**-middle shelf
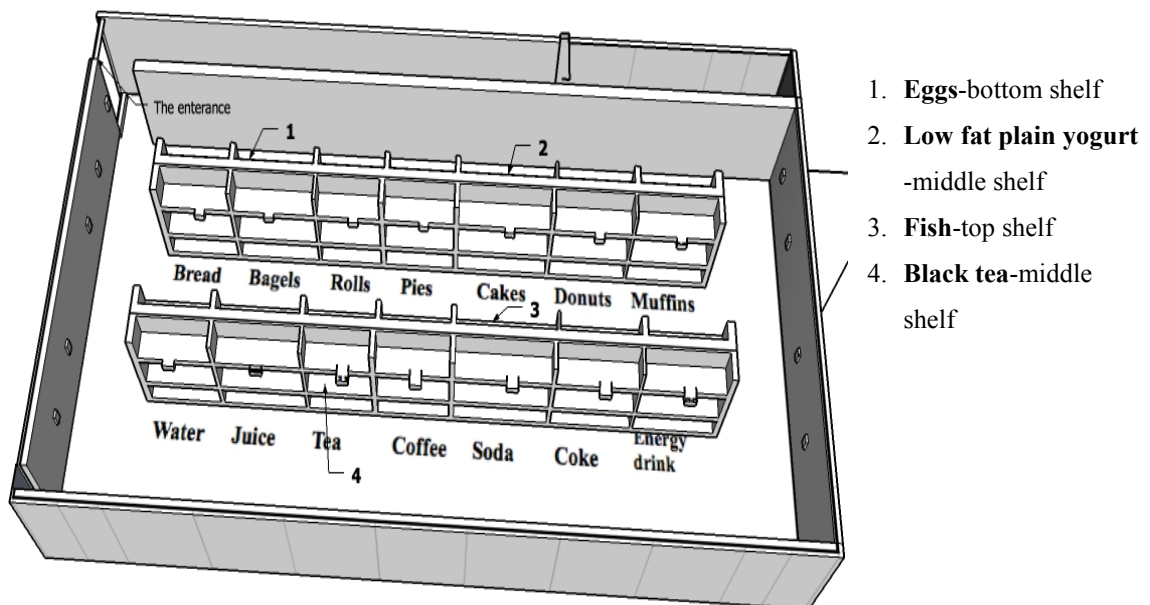
Figure 41. The mock grocery store

5.1 Goals of the evaluation

We ran an initial evaluation where we used the three categories of sight defined previously to try out the "VirtualEyez app" proof of concept. The objective of the study was to obtain users' feedback pertaining to the application, including suggestions for improvements, in order to learn which design features users found helpful. We also tried to gain information as to how people used the devices and tags and how easy the system was to use.

5.2 Recruitment of participants

The participants were recruited in Halifax, NS, with the assistance of the local CNIB center. We sent out a recruitment email to CNIB clients and volunteers to inform them about the goal of the study. We held a half hour information session at the CNIB centre to explain the study and to answer questions. Participants then signed up to do the study.

Participants were selected based on age (over 18 years old), visual impairment level and smartphone experience. Participants included not just the visually impaired but also individuals with normal sight to collect a variety of opinions regarding the system. We conducted our study with 9 participants with 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) (as shown in Table 2).

Table 2: Participants' demographic data

Participant number	Age	Gender	Vision level	Using guide
P1	48	Male	Visually impaired	A cane
P2	50	Male	Totally blind	A cane and a dog
P3	34	Female	Totally blind	A dog
P4	71	Female	Totally blind	A cane
P5	32	Female	Totally blind	A cane and a dog
P6	47	Male	Totally blind	A cane
P7	71	Female	Sighted	None
P8	38	Male	Visually impaired	None
P9	30	Male	Sighted	None

Individuals with vision loss were selected and grouped based on the following classifications:

• *Blind:* A person who has completely lost his/her vision and, as such, has no capacity to use the sense of vision when doing tasks (Blom, 2003).

• *Visually impaired:* A person who has limited vision, such that he is unable to read writing and easily orient himself using visual cues, but does have some vision and therefore some capacity to use vision in doing tasks (WHO, 1992).

5.3 Study Process

After the information session, participants who were willing to participate in this study signed the consent form that was the read it aloud for all the participants (Appendix A).

Participation in this study was voluntary and partiapants were not compensated for participating.

The study itself took about 45 minutes to complete per participant:

- 5 minutes for providing consent
- 5 minutes for the background questionnaire (see Appendix B).
- 3-5 minutes for training (i.e. opening the application, recording the selected item, retrieving audio instructions, retrieving the visual map, and touching the NFC tags) (as shown in Figures 20 - Figure 39).
- 5-10 minutes to perform the tasks
- 10-15 minutes for the post-study interview

During the experiment participants performed the following tasks:

We asked participants to perform four tasks. They were asked to find eggs, low fat plain yogurt, fish and black tea respectively as can be seen in Figure 41. We made sure that the different products were on different locations on the shelves to try to better mimic a true grocery store experience. For example, eggs were located on the bottom shelf, low fat plain yogurt was located on the middle shelf, fish was located on the top shelf, and black tea was located on the middle shelf (see figure 41). We also had participants actually remove the item from the shelf and carry it in a bag while they did all four tasks.

5.4 Task Steps

1. The participants used a mobile device to scan the NFC Tag, which was placed at the entrance of the store.
2. The participants recorded his/her shopping purchase in the smartphone app using voice recognition or by typing the list.
3. The participants followed the path on the map to reach their items. The map is supported by voice commands to help people with visual impairments navigate through the store.

4. If the participants got lost, they could touch any NFC tags, which are prominently displayed in the grocery store, to update his/her path. Blind people could touch any walls, aisles or shelves near them in order to find the prominent NFC tags and then scan it with their device.

5. Participants could obtain the exact locations of the selected items by listening to the audio message (e.g. the item is on the top shelf).

6. The participants were also able to listen to or read general information about their items (e.g., color, size, and ingredients), and find nutrition facts information. This is because each shelf has an NFC tag and the application can read it when the customer scans the tag.

At the start of the study, each participant was directed to the front of the grocery store (near the entrance) and was given a plastic bag to carry. Then each participant was asked to find the four items from different locations within the store. We did not control for order during performance of the task. In the case of blind participants, individuals were allowed to use an aide (e.g., guide dog or white cane) after receiving directions from their smartphones. Each participant had a bag while performing the task. After the participants bought the four items from the mock grocery store, each participant answered the interview questions regarding their opinion about the application (Appendix C).

During the experiment, when the participant picked up all four items, the researcher checked that he/she had selected the correct four items. The researcher took notes regarding where the participants had faced difficult times in achieving the tasks. She also recorded how long it took for participants to find all the four items.

5.5 System Evaluation

In order to evaluate the usability of the VirtualEyez system, we collected quantitative (time to do tasks) and qualitative data (questionnaires, observational notes and interviews). We used three main data collection methods during this study for gathering data and analyzing the results:

- The pre-study questionnaire had 3 main sections. The first section contained demographic questions, such as age, gender and vision level. The second section focused on the difficulties that the participants face while buying their groceries, and the third section pertained to the solutions that they have used to overcome these difficulties (see Appendix B).

- Observational notes were used when the participants were asked to buy the 4 items. During the tasks, the researcher took notes and no video was recorded:

    1. How long each participant took to buy 4 items while using the VirtualEyez app?

    2. Any request for assistance during the experiment?

    3. Any difficulty that participants had when collecting an item from the top, middle and/or bottom shelf?

    The observational notes were used to further help us identify any difficulties that the participants faced in using the application to find their products, which we asked participants about during the interview.

To analyze the observational notes we transcribed the notes for each participant into a word document and grouped together similar observations.

- The post-study interviews were audio taped (see Appendix C) and used to obtain user feedback about the application and the users' level of satisfaction. In particular, the interview sought to get specific participant opinions on the VirtualEyez system as well as their suggestions for improving the application.

Overall, the interview and notes indicated the level of satisfaction with the application among sighted, visually impaired, and blind individuals, and provided critical indications about how the application might be improved in order to make it most effective.

5.6 Summary

In this chapter, we discuss the experimental environment and the main tasks that participants performed during the experiment. We explained how we collected the data using three methods include a pre-questionnaire, observational notes and a post interview in order to evaluate the usability of the VirtualEyez system, as well as to better understanding users' behavior while using the app.

CHAPTER 6: RESULTS AND DISCUSSION

6.1 Results

The goal of this study was to determine if the VirtualEyez system is useful as an aide in grocery shopping and, in particular, to examine the degree to which different groups (blind, visually impaired, and sighted) might benefit from the application. We used a variety of methods, both qualitative and quantitative, to assess the application. Several factors were considered with regard to their possible effect on the usability of the VirtualEyez system, including age, gender, vision level, and navigation assistance (a cane, a dog, both or none). Consideration was also given to participants' usual difficulties while buying groceries and their current use of supportive systems and accessibility services. In addition to the data generated by the questionnaires and interviews, we also measured the time taken to acquire the items and whether or not participants asked for assistance during the experiment.

6.1.1 Pre-study questionnaire

The pre-study questionnaire asked participants about the participants' demographic data including age, gender, vision level and whether the participants use a guide during navigation indoors. It also inquired about the main challenges facing participants while grocery shopping and how they overcome these challenges. The last part of the questionnaire asked about how participants interact with their mobile phone and which types of accessibility services they use.

Only one visually impaired participant used a cane to get around and to help him avoid obstacles. The other visually impaired participant does not use a cane because he has enough vision to see the obstacles in his way. Two of the blind participants can use either a cane or a guide dog to navigate. During the study two blind participants used a dog to navigate through the store to help them avoid obstacles. The remaining totally blind participant used a cane.

Table 3: The difficulties participants face in grocery store

Participant number	Difficulties		
	Finding a specific product	Distinguishing canned products	Navigating through a grocery store
P1	Yes	Yes	Yes
P2	Yes	Yes	Yes
P3	Yes	Yes	Yes
P4	Yes	Yes	Yes
P5	Yes	Yes	Yes
P6	Yes	Yes	Yes
P7	Yes	Yes	Yes
P8	Sometimes	No	No
P9	Sometimes	No	No

The questionnaire revealed a number of trends regarding grocery-shopping difficulties (see Table 3):

- The visually impaired and blind participants had difficulty finding specific items quickly in a grocery store. Sometimes the sighted participants faced this type of challenge as well.
- Both the visually impaired and blind participants found it difficult to recognize and distinguish different canned products.
- One visually impaired participant and all blind participants had difficulty navigating through grocery stores. The second visually impaired person stated that he has enough vision to see which aisle he is in and the obstacles in his way.

The questionnaire revealed a number of trends regarding how participants address these challenges:

Table 4: The solutions have used to overcome the difficulties

Particip- ant number	Solutions				Using Accessibility	
	Asking the cashier	Hiring assistance	Using a delivery service	Using a shopping assistance system	TalkBack	Magn- ifier
P1	No	Yes	No	No	No	Yes
P2	No	No	No	Yes (i.d. mate Quest)	Yes	No
P3	Yes	No	No	No	Yes	No
P4	Yes	No	No	No	Yes	No
P5	No	No	No	No	Yes	No
P6	Yes	No	No	No	Yes	No
P7	No	No	No	No	No	No
P8	Yes	No	No	No	No	Yes
P9	Yes	No	No	No	No	No

- Participant 8 prefers not to ask customer service for help to find his items due to the long wait that can be involved. He stated that because he looks like a normal person, when he asks for assistance to find a product, the clerk tells which aisle the item is in, requiring him to tell him or her that he is visually impaired and needs someone to show him the exact place. On the other hand, participant 1, who is visually impaired person, he usually asks for help from the clerk, especially if the product is new, and he said that he too has to tell the clerk in the store that he is visually impaired because he appears to have normal vision. While three of the blind participants regularly ask for such assistance, the other two do not.
- Surprisingly, all participants reported that hiring assistants and using delivery services are not good solutions for doing grocery shopping, primarily for financial reasons.
- Participant 2 had used a supportive system at home and he had never used it in grocery stores. The system is called i.d. mate Quest, which is a barcode scanner that helps

visually impaired people to identify items by scanning the item's barcode. This system uses both text-to-speech and voice recording technologies (En-Vision America, 2014).

▪ All visually impaired participants used a magnifier service to enlarge the size of text on the screen and more easily read the content of messages and button labels, and all the totally blind used the TalkBack service to interact with the devices.

▪ Not surprisingly, most blind individuals use voice recognition, sometimes in combination with typing, to enter product information, while the others relied primarily on typing (Figure 41).
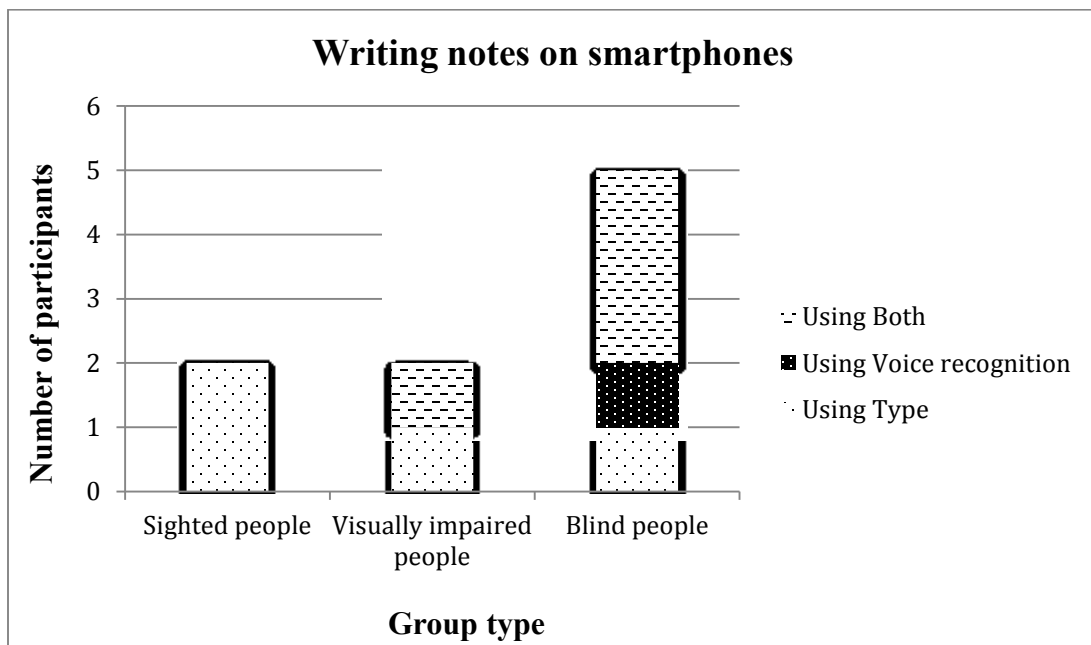
Figure 42. Writing notes on smartphones

6.1.2 Observational notes

The observational notes were used to figure out whether the participants required help during the experiment and to determine which shelf levels provided the most difficulty for each participant.
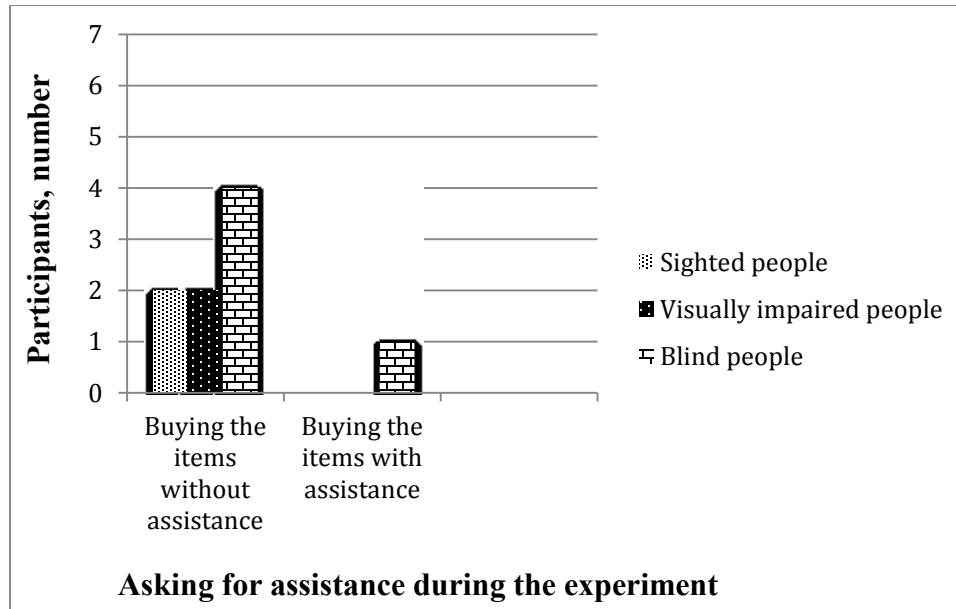
Figure 43. Did the participants ask for assistance during the experiment?

Although all of the participants were able to successfully complete the task of buying the four items, the time required to do so varied (Figure 43). Eight participants were able to find the four selected items without asking for assistance and the ninth participant, who has both a vision and hearing impairment, asked for assistance.
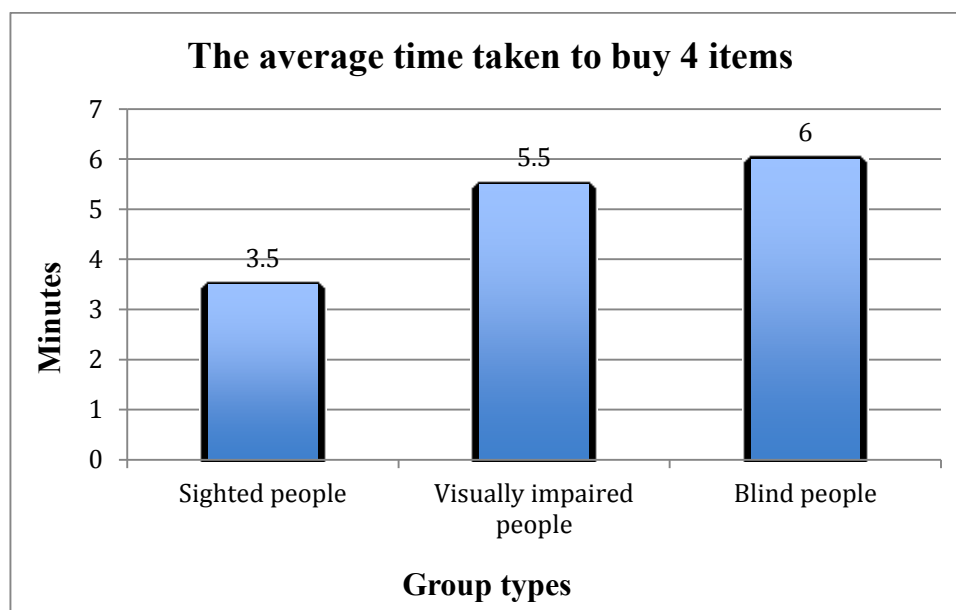
Figure 44: The average time taken to buy 4 items

The time required to find the four items ranged between 3 and 4 minutes for the sighted participants, between 5 and 6 minutes for the visually impaired participants, and between 4 and 13 minutes for blind participants (Figure 44). The blind participant who took the most time of anyone, 13 minutes, also has a hearing impairment that made using audio instructions difficult; as a result, he proceeded by randomly touching NFC tags until he reached the correct items by chance. Consequently, we removed her time data when we figured out the average time in Figure 44. However, the time data was not recorded as precisely as it could have been, and is not completely generalizable as it would be if we had evaluated the app in a real grocery store, since this mock grocery store had only four aisles and no customers, noise, or obstacles.

The notes show that no participants faced difficulty finding the exact location of the product (on top, middle and bottom shelves). One participant said that the app addressed the problem of finding items at low and high levels.

6.1.3 Interviews

6.1.3.1 Interface features

1. Buttons

Interview responses revealed overall satisfaction with the application and its effectiveness as a shopping aide. The visually impaired participants found the buttons to be well organized and easy to find. Participant 1 stated, "…there were not many buttons. It is a simple interface. The button size was great. The color was good. Good contrast" and participant 8 said "the buttons were large and I could actually see them clearly." He also suggested placing one button on each page to make it large enough for them to see. They also found that the function of each button was easy to understand. The totally blind participants also found the buttons were easy to find with the support of the TalkBack service, with the recommendation of placing the buttons in two rows at the bottom of the screen. Participant 2, who had no vision, suggested eliminating the location button and

letting the shoppers obtain the spoken direction commands automatically after touching the NFC tags. Participant 6 stated, "…the function of each button was easy to understand. The app spoke the name of the button and then basically the name explains what it did". Sighted people also found them to be well organized. One sighted participant liked the fact that the app provided two ways (visual and auditory) to find the buttons.

2. Location Button

Both of the visually impaired participants found that the location button was helpful. Participant 1 reported, "…the location button was helpful. I like the fact that once I touch the NFC tag I can know where I am and update the direction." All the blind participants found the location button helpful with the recommendation to make the direction commands speak up without the requirement of pressing the location button. Participant 3 reported that "it was helpful, I was able to check where I was. When looking for a product I was able to tap the location button and then find out exactly what product I was at and then guide me to the next product."

3. Visual Map

The sighted people preferred to use the visual map, and there was no need to use the location button; they found the visual map easy to follow. The remaining participants did not use the visual map. They also found the text sizes of the button label, product information and alert message contents on the mobile screen were clear, as were the colors.

4. Sound

The visually impaired participants found the sound used in the VirtualEyez system was clear and easy to follow, but they found it to be too slow. Four of the blind participants also found the sound was clear, but wanted the ability to be able to adjust the sound speed. The fifth blind participant (participant 4) found the sound was unclear due to a hearing problem; he could hear the app when it read one word like the name of the section, but he could not hear the app while it read the direction commands.

6.1.3.2 NFC tags locations

Following the direction commands and NFC tags was easy for all participants, especially because the tags are located at eye level. Participant 1, who is visually impaired, found locating the NFC tags on the top shelves was quite easy because he noticed that the shelf color was black and the NFC tag color was white, and this contrast made it possible to locate the tags visually.

The two participants who are visually impaired felt that they bought their desired items faster than usual. Participant 1 said, "If it is something new I have never purchased, I can spend an hour looking." Participant 9, who is a sighted participant reported that "I cannot say it is faster or not because the store here is small."

6.1.3.3 The advantages and disadvantages of the VirtualEyez system based on participants' feedback

All participants reported that the VirtualEyez system assisted them to collect the four chosen items in an independent manner. Participant 5 said "The app gave me very specific directions where the items are located, so including what items I would pass to get to it. If I use it in the grocery store, I would not have to ask anyone for help." Participant 8 stated, "I find it really challenging see prices and labels. By using this app I can do it faster. Usually I only get things I know how much they are." Participant 7, who is a sighted person, reported that sometimes she faces a challenge to find an item after the items' locations are changed. By using this system, the store would have to keep the item in the same place, which would definitely address her challenge.

All participants found the user interface was easy to use. Participant 1, who is visually impaired participant found the TalkBack service helpful and reported that using it several times would assist him in memorizing the location of the buttons. Participant 8 prefers to use the magnifier (Zoom) to enlarge the text size on the screen. Participant 2, who is bind person, stated that "It was not easy at first, the dots helped me." He suggested bringing the buttons nearer to each other, so users do not have to jump from the top of the screen

to the bottom.

When asked about the benefits of the system, all participants found that it will aid shoppers in two ways: increased independence and reduced shopping time. The visually impaired and totally blind participants felt that this app has the potential to help people with low vision to make decisions regarding what they want to buy because this system will tell them the price and nutrition facts via the description button. They also found the location button was helpful as it tells them what products they pass by, potentially reminding them of items they have forgotten. Participant 4 reported, "I never go shopping by myself. This app is helpful" and participant 5 stated that "I think the biggest benefits, it would allow me to shop independently, without searching for the barcode, without requiring assistance from the store staff, which sometimes take a long time. Once I use it in the store it will help me a lot because I'll get used to it and the layout. Then it will be so easy for me to navigate and find the product." Participant 2, who is totally blind, liked that the app gives such explicit location directions, including which shelf level. Participant 7, who is a sighted participant liked the app because it told her what is inside the store, so she did not have to spend time looking for items that may not be in stock.

The two main concerns for visually impaired people are knowing the price of the items and saving their time. After using the app, all visually impaired participants reported that the VirtualEyez system addresses their grocery shopping concerns, since scanning barcodes will not tell them the price and other information. A visually impaired person (participant 8) stated that using this app in grocery stores is better than using it other stores because grocery stores have so many products that it is difficult to shop.

The system also addressed the concerns of the totally blind regarding grocery shopping. Participant 5 also reported, "It addresses my concerns about the price and nutrition facts, which I was not really expecting. It tells me what is in the aisle, so if you want to browse the aisle you can touch the tag to know exactly what type of items are in the aisle."

The experiment was designed to measure the weaknesses and strengths of the VirtualEyez system, and it did succeed in highlighting some issues faced by the participants while using the system. The most significant issue brought up by three blind participants during the interview was that there is no system to help them avoid obstacles. In a real store, the employees usually put some sale boxes and new stock in the aisle; participants noted that a successful system must have a way to overcome that. Another issue is that blind participants have to a carry mobile phone in addition to a shopping basket, which could prove difficult in combination with a cane or a guide dog. Thus, it may be necessary to reduce the physical burdens in the system in order to accommodate those with such visual aids. One difficulty faced by a visually impaired participant (Participant 8) was understanding the voice, mainly because he usually uses magnifier to enlarge the text and never uses the TalkBack service. Participant 3, who is a totally blind participant, found that the speech recognition service did not work perfectly, such that she had to repeat the product name until the system successfully registered it.

6.2 Discussion

The VirtualEyez is a proof-of-concept prototype designed to be implemented in grocery stores for the benefit of shoppers, especially those with visual impairments. The purpose of this study was to test the VirtualEyez system in a grocery shopping environment in order to determine whether or not it effectively helps visually impaired shoppers find items, and to identify the system's strengths and weaknesses. The overall impression of the VirtualEyez system provided by participants following the experiment was positive, with shoppers indicating that it was easy to use and helped them in their grocery shopping.

The overall results indicate a serious need to enhance the app user interface to be straightforward to easily serve blind and visually impaired people. The results of the pre-study questionnaire indicate that there is a need to design an assistive shopping system to help visually impaired and totally blind shoppers overcome the challenges they usually encounter when buying items. As they stated, most solutions they use do not meet their

demands. Participants also said that they consider time and cost of delivery service, hiring assistants and shopping assistive system to be the most important factors, therefore they do not prefer to use these solutions. We should therefore consider these two factors carefully when improving the system.

The observational notes show that eight participants bought the four items without any difficulty and without asking for help. Although the one participant with both a vision and a hearing impairment (participant 4) asked for assistance, that indicates a new direction for future work – to enhance the system for people with multiple disabilities by using other features such as vibration. In addition, the observational notes indicate that the VirtualEyez app may address the issue of locating the product on different shelves (top, middle or bottom).

The VirtualEyez system has features existing shopping assistance systems do not have, such as using users' familiar smartphones, carrying less technology, scanning NFC tags, gaining immediate update to direction commands, and providing both an identification and navigation system to help overcome other system limitations. For example, the Trinetra system asked the blind users to locate the barcode on a grocery product – a task that is very challenging because the user cannot find the barcode by touch. In addition, the systems that use barcode readers do not provide information about the price of the products. Indeed, a positive aspect of this system is that it requires no extra equipment (e.g., RFID or barcode reader). With many existing systems, the user must wait for the identity of the product to be sent to a remote server; the VirtualEyez system avoids this potential delay by providing immediate responses via NFC tags. This system also has the advantage of lower cost compared to other systems because of the use of inexpensive passive NFC tags. Lastly, VirtualEyez may assist various groups of people – not just blind and visually impaired individuals but also those who are sighted.

Suggested improvements

Although participants were happy with the assistance provided by the VirtualEyez system, participants had some suggestions for improving the application. One common request, made by three blind participants, was to add the ability to adjust the speed of speech, so that they would not have to waste time listening to directions that were unnecessarily slow. There were also some suggestions regarding the interface, such as eliminating or changing the locations of certain buttons. The sighted participants suggested that this app could be further utilized to provide information about items on sale, possibly by tapping NFC tags at the beginning of each aisle to find out about on-sale items. Additionally, participant 2 asked to use "get direction" as a label for the second button instead of "get path".

6.3 Limitations

The ability to draw firm and broad-ranging conclusions from this study is inhibited by its various limitations. For example, as one sighted participant pointed out, the mock grocery store used was small, with only four aisles. Additionally, the task of finding four items is unrealistically small compared to how many things one buys on a typical grocery store visit. It is likely that testing the application in a real store would reveal some other issues and challenges, possibly related to differences not reflected in the mock store (e.g., the doors – rather than shelves – of the refrigerated sections). Perhaps the most notable limitation of the current study is the small sample size: with only nine participants across three different conditions, it is virtually impossible to draw generalizable conclusions or get an exhaustive overview of what works well and poorly.

While the VirtualEyez system may benefit a number of populations – not just visually impaired and blind people but also sighted individuals –it may not be of use to individuals with other deficits in addition to vision problems. For example, one of the participants in this study, who had both a visual and a hearing impairment, was unable to take full advantage of the system and resorted to random searching for the products.

Thus, VirtualEyez may not help individuals with problems that interfere with their ability to utilize the system's functionality.

As stated above, the small number of participants in each group prevents generalization of these findings to all shoppers with low or no vision. Nevertheless, we have demonstrated VirtualEyez may be a usable system that aids shoppers with vision problems.

6.4 Design Recommendation

After performing this initial evaluation and discussing the app with the participants, we have made several design recommendations for other designers who may be developing apps to assist blind users and or visually impaired persons with their everyday activities.

For blind people:
- Make it possible for the user to adjust the reading speed. The reading speed should not be fixed and should be personalized by user.
- Use TalkBack service and Text-to-Speech service to enable blind users to access mobile screen content.
- Add a voice recognition service to make text entry easier and faster for people with no vision.
- Increase object size (e.g., large buttons) to aid people with poor or no vision since they may be less precise in pointing to specific parts of the mobile screen.
- Reduce the number of buttons and place them in the bottom of the screen.
- Put the main button in the bottom of the screen.

For visually impaired people:

- Use large fonts to make it easier to see.
- Place one button in each page and make it large to enable them to see it without enlarge the user interface size.
- Provide good contrast to users distinguish between the screen's background and interface items (e.g., buttons).

- Allow the app to access a Magnifier service to allow them to enlarge the content of the screen.

6.5 Summary

In this chapter, we discussed the results of the study, including the pre-experiment questionnaire, the experiment itself, and the interviews asking the participants about their experiences with VirtualEyez. In doing so, it details the particular strengths, weaknesses and suggestions mentioned by the participants in those interviews. In discussing the results, this chapter addresses the implications of the findings, as well as its limitations.

CHAPTER 7: CONCLUSION AND FUTURE WORK

Visual impairment, on the rise throughout the world, impacts all aspects of people's lives, including such routine tasks as grocery shopping. Thus, there is a growing need for assisted shopping solutions with the potential to improve the independence – and, therefore, quality of life – of visually impaired individuals. This thesis proposed a novel system, VirtualEyez, to help people with vision disabilities navigate through a supermarket and locate their products. The VirtualEyez system is capable of providing three needed functionalities. Firstly, VirtualEyez checks the availability of the selected item. Secondly, the app provides indoor navigation using the NFC tags, and calculates the optimal route using the Dijkstra algorithm. Thirdly, it provides product identification, including the name of the selected item and a variety of general information about the selected product.

One of the most novel aspects of this system – and this study – is the use of NFC technology, which provides a reliable, low cost indoor navigation system as well as an identification system. Crucially, use of NFC tags eliminates much of the delay time associated with other systems because information can be transferred directly from tag to smartphone rather than relying on access to separate servers and networks. In reducing the wait, the use of NFC technology addresses one of the biggest complains of shoppers using such systems and clearly contributes to the quality of life improvement promised by VirtualEyez.

The VirtualEyez system was evaluated in a mock grocery store setting set up within the CNIB center. The evaluation helped us identify the features of the VirtulEyez prototype and provide information for the developers. The study also found that audio and visual data received from scanning NFC tags may assist users for shopping.

The main contribution of our research is using 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 while grocery

shopping. The initial evaluation received positive feedback and provided some improvements for the system. Based on this evaluation we have suggested 3-4 design recommendations useful in creating apps for blind and visually impaired users.

There are various ways in which VirtualEyez could be expanded upon in order to increase its usefulness. The VirtualEyez system currently works only for a single door layout but may be extended to multi-door buildings, such that the navigation would be possible in entire buildings, with elevators and emergency exits taken into account. Indeed, the VirtualEyez system will be extended to support the building with multiple floors.

There is a need for future work to more thoroughly evaluate VirtualEyez, using a larger and more representative sample of sighted, visually impaired and blind individuals. There is also a need to add an obstacle avoidance application to the VirtualEyez system in order to make the system more effective. We would like also to develop this system to support different languages. For example, if a user went to an Arabic grocery store they may want to be able to get items without needing to understand the labels of the products. In general, we hope to improve the application in ways that are in direct response to feedback we received in this study.

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DALHOUSIE UNIVERSITY
Inspiring Minds

Project Title: VIRTUAL-EYES: DEVELOPING NFC TECHNOLOGY TO ENABLE THE VISUALLY IMPAIRED TO SHOP INDEPENDENTLY

Researcher:

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Supervisor:

Dr. Srini Sampalli, Faculty of Computer Science, Dalhousie University

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We invite you to take part in a research study being conducted by Mrim Alnfiai, student in the Master of Computer Science program at Dalhousie University. Taking part in the research is up to you; it is entirely your choice. Even if you commence participation, you may leave the study at any time for any reason. If you decide to stop participating at any point during the study, you can also decide whether you want any of the information that you have contributed up to that point used in the research. You have the complete right to withdraw from this study at any time without penalty, even after signing the letter of consent. You have also the right to refuse to answer any questions without penalty and may continue to be a part of the study.

A researcher is always available over the study period by email or in person to answer any questions you may have or address any problems that you may experience with the tasks. To be eligible to participate in the study, you must have an experience using a smartphone. The study is described below. The information below explains any benefit, risk, inconvenience or discomfort that you might experience during participation. It also outlines what is involved in the research and what you will be asked to do as a participant. Participating in the study may not benefit you directly, but your participation may benefit others. You should discuss any questions you have about this study with Mrim Alnfiai.

The purpose of this study is to evaluate a supportive system that will assist people with navigation in a grocery store, identification products, and obtaining general information about each product. The aim of our system, named Virtual-Eyes, is to help improve the ability of a person with visually impairments to overcome some of the challenges of navigating a grocery store and identifying products. This application may also help sighted people buy their items more quickly. The purpose of the study is to help the researcher identify the strengths and weaknesses of the application and receive feedback on the usability of the application. You will be asked to participate for an hour and half where you will perform a set of tasks (for example, find five items from a temporary grocery store such as, chocolate milk, tea, sugar, chicken and white bread).

At the beginning of the study, you will meet with a researcher (in the Canadian National Institute for the Blind (CNIB) centre). At this initial meeting you will be asked to give consent to do the study and once the consent is received you will fill in a background questionnaire detailing your experience with using smartphone applications and how you usually buy items from a grocery store. The researcher will give you a general description of the type of tasks to be completed during this study. After doing a set of tasks, you will participate in an interview asking your opinions about the usability of the Virtual-Eyes system. During the study, researcher will take notes about what was observed.

All personal and identifying data will be kept confidential. Anonymity of textual data will be preserved by using pseudonyms, such as ID numbers. All data collected in the notes, questionnaires and interviews will use pseudonyms to ensure your confidentiality. The informed consent form and all research data will be kept in a secure confidential location for 3 years in accordance to the Dalhousie University policy.

I agree that the Virtual-Eyes system and benefits of this system have been explained to me. I have had the chance to ask questions and to receive any requested additional details about the study. I understand that I may withdraw from the study at any time without penalty by communicating with the researcher. I understand that by signing this consent form, I am not waiving my legal rights or releasing the investigator(s) or involved institution from their legal and professional responsibilities.

I, _____, agree to the conditions stated in this letter of consent and certify that I have received a copy of the consent form. Questions concerning the study can be directed to the researcher (Mrim Alnfiai, Master of Computer Science Candidate) at (+1 902 4522017) or (mr275603@dal.ca). In the event that you have any difficulties with, or wish to voice concern about any aspect of your participation in this study, you may contact Catherine Connors, Director, Office of Research Ethics Administration at Dalhousie University's Office of Human Research Ethics for assistance: phone: (902) 494-1462, email: Catherine.connors@dal.ca

Signature Page
Project Title: VIRTUAL-EYES: DEVELOPING NFC TECHNOLOGY TO ENABLE THE
VISUALLY IMPAIRED TO SHOP INDEPENDENTLY
Lead Researcher: Dr. Srini Sampalli, Supervisor**,** srini@cs.dal.ca
Mrim Alnfiai, Researcher, mr275603@dal.ca

"I have read the explanation about this study. I have been given the opportunity to discuss it and my questions have been answered. I agree to take part in this study. I realize that my participation is voluntary and that I am free to leave the study at any time."

Participant   Researcher
Name: _____   Name: _____
Signature: _____   Signature: _____
Date: _____   ***Date: _____***

Please select one of the options below:

☐ *"I agree to let you directly quote any comments or statements made in any written reports without viewing the quotes prior to their use and I understand that the anonymity of textual data will be preserved by using pseudonyms."*

Participant   Researcher
Name: _____   Name: _____
Signature: _____   Signature: _____
Date: _____   *Date: _____*

☐ *"I do not agree to let you directly quote any comments or statements made in any written reports without viewing the quotes prior to their use and I understand that the anonymity of textual data will be preserved by using pseudonyms."*

Participant   Researcher
Name: _____   Name: _____
Signature: _____   Signature: _____
Date: _____   *Date: _____*

☐ *"I agree that the researcher may record the interview with me."*
Participant   Researcher
Name: _____   *Name: _____*
Signature: _____   *Signature: _____*
Date: _____   *Date: _____*

☐ *"I agree that the researcher may assist me to fill out the questionnaires."*
Participant   Researcher
Name: _____   *Name: _____*
Signature: _____   *Signature: _____*
Date: _____   *Date: _____*

APPENDIX B: PRE-QUESTIONNAIRE

The following questionnaire has been prepared by Mrim Alnfiai who is a Master of Computer Science student at Dalhousie University. Please do not write your name on the questionnaire since all responses are confidential and anonymous. This questionnaire is strictly voluntary. Feel free to leave any questions blank.

1. Age: _____

2. Gender: ☐ Male ☐ Female

3. I am presently:
☐ Totally blind
☐ Visually impaired
☐ Sighted
☐ Other: _____

4. Do you use any guides to help you get around?
☐ A dog
☐ A cane
☐ None

5. In a grocery store, finding a specific product quickly is difficult.

☐ Strongly agree
☐ Agree
☐ Neither agree nor disagree
☐ Disagree
☐ Strongly disagree

6. It is difficult to recognize and distinguish products from each other.

☐ Strongly agree
☐ Agree
☐ Neither agree nor disagree
☐ Disagree
☐ Strongly disagree

7. It is difficult to navigate through a grocery store.

☐ Strongly agree
☐ Agree
☐ Neither agree nor disagree

☐ Disagree
☐ Strongly disagree

8. Asking the cashier is a good solution for purchasing my items from a grocery store.

☐ Strongly agree
☐ Agree
☐ Neither agree nor disagree
☐ Disagree
☐ Strongly disagree

9. Hiring assistance is a good solution for guiding me in a grocery store.

☐ Strongly agree
☐ Agree
☐ Neither agree nor disagree
☐ Disagree
☐ Strongly disagree

10. Do you use delivery service?

☐ Yes
☐ No

11. If you answer question 10 yes, how is it?

☐ Good
☐ Bad
☐ Okay

12. If yes, Please identify the drawbacks and benefits of this service?

Drawbacks

☐ Expensive
☐ Not on time
☐ Not available every day

Benefits

Technical skills

13. Tick any supportive technologies you are using to be independent:

- ☐ Robo-Cart system
- ☐ BlindShopping system
- ☐ ShopTalk system
- ☐ ShopMobile1 system
- ☐ ShopMobile 2 system
- ☐ iCare system
- ☐ GroZi system
- ☐ None
- ☐ Others …………………………………………………..

14. List all devices, apps and services that helped you identify items from a store?

- ☐ Trinetra system
- ☐ Mobile Sales Assistant
- ☐ HearMe system
- ☐ Ubiquitous system
- ☐ None
- ☐ Others …………………………………………………..

15. Do you navigate with smartphone apps using Accessibility?
- ☐ Yes
- ☐ No

Others: ………………………………………………………

16. How do you write a note on smartphone apps?

- ☐ Type

- ☐ Voice recognition

APPENDIX C: POST-STUDY INTERVIEW

1. Do you feel that you successfully bought your purchases by using the Virtual-Eyes system?

2. In relation to other systems you have used, did you find the application, Virtual-Eyes, prototype to be easy to use? Why? Which other systems have you used?

4. Did you feel the buttons well organized and easy to find? Why?

5. Was the function of each button easy to understand? Why?

6. Did you find the "Location" button was helpful? Why or why not?

7. Did you feel the sound used in the Virtual-Eyes system was clear? Why?

8. What is your opinion about the map of the grocery store**?** Was the direction from the source to destination accurate and easy to follow? Was the color of the route on the map clear? Why or why not?

9. Was the text size of the button label, product information and alert messages contents on the mobile screen clear?

10. Do you think the NFC tags' locations were appropriate? Why or why not?

11. For sighted people, did you feel your shopping was faster than usual? Why?

12. Did the Virtual-Eyes system assist you to get the product independently? Why?

13. What is your overall impression of the Virtual-Eyes prototype?

14. Was the Virtual-Eyes user interface easy to use?

15. Did you have any difficulties when you used the system? What were they and why do you think that you had this/these problems?

16. Do you have any suggestions to fix these problems?

17. What do you think the benefits of this system are?

18. What overall suggestions do you have for the system?

19. Did this system address your grocery shopping concerns? How and what didn't it address?