Cricking Implementation with Augmented Reality and RFID

Towards Independent Living of People with Motor Disabilities

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DOCTORAL THESIS UPF / YEAR 2015

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Acknowledgments

First and foremost, I deliver my humble and earnest thanks to the Almighty Allah for showering His blessings in every possible form upon me. He gave me strength, courage, patience and introduced to me all those people who made my studies and stay in Spain a pleasant experience. Without His help I could not have made any step forward.
This dissertation signifies an enormous deal of time and effort not only on my part, but also on part of my thesis advisor, Prof. Rafael Pous. I am grateful for the time and advice that you provided me over the past three years. This thesis owes much of its contents to your ideas and guidance. You helped me in shaping up my research from day one, pushed me to get through the foreseeable research setbacks, and encouraged me to achieve the best of my aptitudes. I would like to put on record the efforts of Dr. Joan Melià-Seguí, former member of our research group in shaping up my articles and thesis. I always found him very positive and helping throughout my PhD dissertation. My sincere thanks goes to Dr. Muhammad Fahim and Dr. Zeeshan Pervez who provided me insightful comments and guidelines to successfully carryout my research tasks.
I am thankful to my other group members for providing insightful and constructive comments to improve the quality of this dissertation, especially to Prof. Enric Peig. I would like to lengthen my thanks to my immediate lab mates Raul Parada, Marc Morenza, Kammarudin Nur and Dr. Anna Carreras and to all my friends and colleagues in UPF, Syed Waqas Zamir, Praveen Cyriac, Gabriela Ghimpeteanu, Raquel Gil and others for their friendship and help to overcome the difficulties throughout my thesis research. I am also grateful to Dr. Iria da Cunha who helped me to bridge the cultural barriers and gave me useful comments to successfully carry out research and teaching tasks at UPF.

Finally, I would like to thank my family, father and mother for their love, prayers, support and encouragement that reinforced my spirit at many crucial situations.

Zulqarnain Rashid
Barcelona, Spain
November, 2015

Abstract

People with manipulative and locomotive disabilities represents a large fraction of the population classified as disabled, including the elder, injured and other health related issues. Wheelchairs have evolved in order to maintain their mobility, autonomy and independence in the society. Despite important achievements in accessibility in current society (e.g. streets adapted to wheelchairs, or public transportation adapted with ramps and elevators), people with motor disabilities still lack independence in daily activities to improve their quality of life. Shopping is one example where users can not access products in shelves beyond their arm length. Due to this barrier they often need personal assistance or support to complete all the necessary steps in the shopping activity. However, wheelchair users may prefer to shop individually (that is, without the assistance) in order to maintain their independence and privacy. This dissertation presents a novel system that allows wheelchair user to interact with items placed beyond their arm length, by means of real-time interactive interfaces collaborated with Radio Frequency Identification (RFID). Our proposal, based on the concept of Smart Spaces, allows the users to interact through Hand-held, Smart Glass or Touch Screen interfaces in real-time with the items present on the shelf. We designed and evaluated the system with the participation of 18 wheelchair users with different degrees of physical disabilities. The obtained results demonstrate the suitability of our proposed system towards an improvement of the independence and empowerment of wheelchair users in shopping activities.

Resum

La gent amb deterioraments locomotrius i de manipulació representa una gran fracció de la població classificada com discapacitada, incloent ancians, lesionats i altres problemes de salut relacionats. Les cadires de rodes han evolucionat per mantenir la mobilitat, autonomia i independència a la societat. Malgrat els importants avenços en accessibilitat a l'actual societat (p.e. carrers adaptats per cadires de rodes o transport públic adaptat amb rampes i elevadors), la gent amb problemes motors encara manquen dè independència en tasques diàries per millorar la seva qualitat de vida. Anar de compres és un exemple, a on els usuaris no poden accedir a productes als prestatges més enllà de la llargada dels seus braços. Degut a aquesta barrera, sovint necessiten atenció personal o suport per completar tots els passos necessaris en una activitat de compres. Però els usuaris amb cadires de rodes prefereixen anar a comprar individualment (això vol dir, sense assistència) per tal de mantenir la independència i privacitat. Aquesta dissertació presenta un nou sistema que permet als usuaris amb cadira de rodes interactuar amb objectes col·locats més enllà de la llargada dels seus braços, a través d'una interfície interactiva en temps real amb la Identificació per Radiofreqüència o RFID. La nostra proposta, basada en el concepte d'espais intel·ligents, permet als usuaris interactuar mitjançant la mà, ulleres intel·ligents o una interfície web a una pantalla tàctil en temps real amb els objectes presents al prestatge. Hem dissenyat i avaluat el sistema amb la participació de 18 usuaris en cadira de rodes amb diferents graus de discapacitat física. Els resultats obtinguts demostren la idoneïtat de la nostra proposta de sistema cap a una millora de la independència i apoderament dels usuaris en cadira de rodes en activitats de compra.

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Chapter 1

INTRODUCTION

1.1 Overview

The popularization of eCommerce has led to effective customer shopping experiences. Pervasive computing could bring the benefits of eCommerce to brick and mortar stores, merging both online and physical worlds into a unique system. We define *crick* as the extension of the (c)lick and b(rick) concept, by means of pervasive technologies. These *cricks* can be performed through diverse interfaces in the retail domain, and automatically receive feedback in different manners [Pous et al., 2013]. We have presented different ways of *Cricking* in our work [Rashid et al., 2014b] [Rashid et al., 2014a].

In this dissertation we will explore in detail, one of the use case of *Cricking* for people with motor disabilities.

In developed countries, citizens with motor disabilities enjoy almost universal accessibility thanks to extensive legislation, technology advancements and consciousness of society. Motor disabled people, like those using wheelchair, are improving their autonomy in everyday activities. For example, we can find reserved sections for the wheelchair users at parking lots, metro, restaurants, touristic spots etc. Accessibility barriers are being overcome for the wheelchair users, mostly regarding accessibility to physical locations.

However, accessibility, that is, the ability to go to places, is only an initial goal. The final objective of citizens with motor disabilities is independent living. By independent living it is generally understood the ability to carry out all or most everyday activities with no or minimum assistance from others. For instance, shopping activities present a disadvantage to wheelchair users, since it may be very difficult (if not impossible) to interact with the products present at the shelf, beyond their arm length. That is, wheelchair users may access the shopping stores with the particular accessibility option, but they cannot reach specific products placed on the shelf without the help or assistance of others, which affects their independence and autonomy.

Online commerce provides people with motor disability the opportunity to obtain virtually any product, also giving the chance to compare, or simply get information without requiring a trip to the store. Nevertheless, online shopping may not be the solution for those people whose goal is not just obtaining a specific product, but who want to be independent in everyday activities just as anybody else.

Our Research is centric on the interactions between people and simple objects as shown in Figure 1.1. We employed the phenomena of Internet of Things (IoT) to provide independent shopping experience to people with motor disabilities. We will use invisible Ubiquitous Computing technology in the store to enable independent shopping for people with motor disabilities. The goal is that in the future a person in a wheelchair will not only be able to access every store, but will also be able to browse every item and make purchasing decisions without needing assistance.

1.2 Motivation and Problem Statement

According to the estimates of World Health Organization (WHO), currently around 1% of the the world population uses wheelchair [WHO, 2012, dis, 2010]. In developed countries, people with motor disabilities are able, for the most part, to live independent lives. They can live independently in their adapted homes, use public transportation, move around city streets and buildings, including the elevators, and in general they can do practically everything non-disabled citizens do, albeit the extra difficulties. Developed countries have passed extensive legislation to the point that inaccessible venues are becoming more the exception than the rule. Accessibility, however, does not always imply independent living experience. The retail store is a very clear example of this situation. Although retail stores are widely accessible, they do not offer them an independent shopping experience for people with visual or mobility impairments. Wheelchair users are limited to browsing the few items that are within their reach, and can-

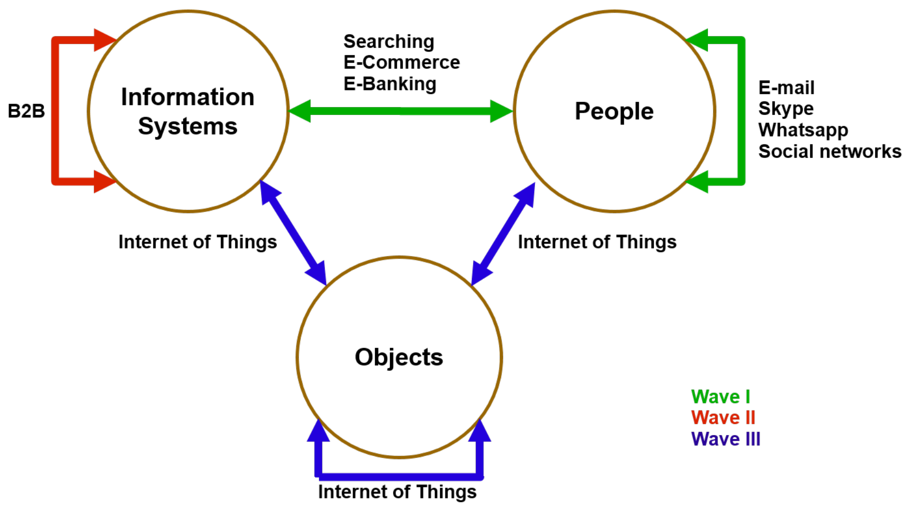

Figure 1.1: Our research focus is on the interactions between people and simple objects.

not examine goods in higher shelves, or those beyond arm's length. Without the intrusive help of someone else, people with serious motor disabilities cannot shop, and independent shopping is one of the last important limitations in what would otherwise be almost independent living. Since shopping is such a central activity in everyone's life, independent shopping is a major problem begging for a technological solution. The good news is that technology exists and it is ready to provide such an independent shopping experience for motor disabled people. The even better news is that this technology will help not only impaired people, but every consumer, with or without disabilities, and will make the retail industry more efficient and competitive. This technology is Ubiquitous Computing. We can effectively elaborate the motivation of the study in a narrative way:

Juan, 25, was the victim of a drink-and-drive accident in which he completely lost the mobility of his lower body. He needs to use a wheelchair to go anywhere. He loves cinema and when he graduates from High School he wants to become a movie director. He is an avid consumer of books, CD's and DVD's. However, he spends more and more time shopping online, because when he goes to music or bookstores he is limited to browsing the limited selection of items within his reach. This excludes any books or DVD's in the top shelves, and practically *every CD in displays whose depth is out of reach to his extended arm. He hates asking for assistance, it takes all the fun out of browsing. Who wants somebody permanently looking over your shoulder? It is fun to talk to the store staff about books, music or movies, and ask them for advice, but Juan would rather shop online than depend on a store clerk for every item he wants to browse. On-line stores, however, are not nearly as fun. Physically being in the store, interacting with staff and with other customers, holding the books and CD's in your hand, looking at the promotional materials, quickly wandering from one item to the next, are all experiences that he had to give up just because of his incapacity to stand up.*

Figure 1.2: Wheelchair users are unable to interact with the items present on the shelf because of their inability to stand.

Figure 1.2 illustrates the problem statement of this study in which wheelchair users are unable to interact with the items present on the shelf .

1.3 Proposed Solution

In this study we will use Ubiquitous Computing technology in the store to enable independent shopping for people with motor disabilities. The goal is that in the future a person in a wheelchair will not only be able to access every store, but will also be able to browse every item and make purchasing decisions without needing assistance.

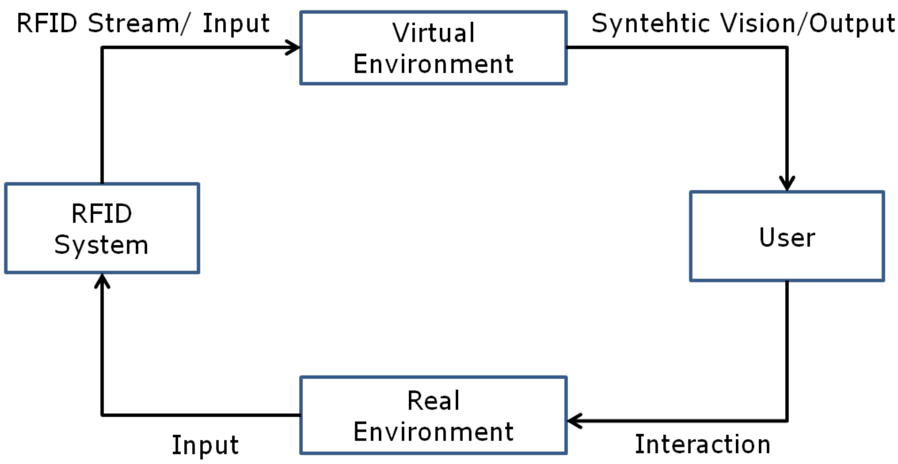

Figure 1.3: Conceptualization of the Proposed Solution.

The different components of the system should work in coordination and seamlessly with each other fulfilling the requirements of ubiquitous computing. The interaction between the different components of the system is shown in Figure 1.3. We propose the synthesis of real and virtual environment through RFID and interaction devices. We divided the system into different components that will be responsible for converting the environment into ambient assisted environment. We propose the use of Smart Spaces based on RFID, in order to inventory and localize the items present in the environment. In Smart Spaces we will have Smart Shelves with the accurate localized inventory. We can then interact with the inventory through different Smart Devices or Hand-held devices.

For instance a wheelchair occupant can interact with items present on the shelf through his Hand-held device while sitting on the wheelchair. We chose different technologies like Smart Phone, Smart Glass for the interaction with the items and their information.

1.4 Contributions

Our contributions in this work are two fold. First, a user study has been conducted on wheelchair users in order to know the feasibility, requirements and usage of the system. The study led us to the categorization of wheelchair users and in shaping their shopping behavior and accessibility issues. In this research, wheelchair users with different degree of hand and arm mobility are selected for further research. Second, we propose an RFID-enabled ambient assisted living system including an RFID-based Smart Shelf, and interactive real-time interfaces developed for different devices. The Smart Shelf is able to inventory and determine the approximate location of all the items, which have previously been labeled with an RFID tag. When objects are added or removed from the shelf, or their location is changed, these events are automatically detected by the RFID system, so that the information provided to the user corresponds to the actual state of the shelf. The interactive interface allows the user to know the current present items, their location inside the store and their location on the shelf. Wheelchair users may not find the particular product they want inside the store, since for them it is difficult and a lot of effort to enter inside the shop, move and communicate. Considering this scenario, two main interfaces are setup, synchronized with each other. The initial interface is placed at the entrance of the store, to provide users with all the information about the items present in the shop, together with their location. The second interface is designed for interacting with each particular shelf within the store, and is to be interacted close to the shelf. Finally, the system is tested and evaluated with wheelchair users in a laboratory simulating a real scenario.

This research is based on a project in a collaboration with a motor disabled people organization/residence in Barcelona, Spain [Res, 2015]. Within this research frame, an initial user study returned two key ideas: On one hand, wheelchair users who want to go shopping, want to do so autonomously and independently, although it may be very difficult for them to interact in the store. On the other hand, different degrees of impairment results in different user requirements, and thus, specific solutions for each user group are required. Three main users groups are identified, leading to three independent use cases built around the same concept of Radio Frequency Identification (RFID) enabled Smart Shelf, and the utilization of Augmented Reality (AR) interfaces, allowing the users to virtually interact (i.e. check product properties, like price, or expiration date) with any product in the store in real-time. The final experience is close to online shopping but in a brick-and-mortar store, which might also improve the shopping experience of the general population.

In this study we summarize the main achieved milestones during this project:

- A preliminary user study on wheelchair users to extract basic requirements for independent shopping.
- Design and implementation of three interaction methodologies based on RFID-enabled Smart Shelves and different interfaces (including AR technologies and Touch Screens), intended for three groups of users with different degree of motor disability.
- The involvement of 18 potential end users in the requirements definition and preliminary evaluation stages.

This study will be a significant endeavor in the promotion of independent and autonomous living among motor disabled people. As the number of wheelchair users are increasing due to certain factors that includes increase in elderly population, accidents etc. It is necessary to increase the social inclusion of wheelchair users in order to maintain a healthy and balanced society. This study will provide a opportunity to the wheelchair users to improve their social inclusion by means of shopping and browsing shelves independently. Moreover this study will benefit retailers by connecting offline and online worlds and bringing online shopping features to the offline retail.

1.5 Structure of the Dissertation

The remainder of the dissertation is organized as follows: Chapter 2 covers the state of the art and discusses available methods for improving the social inclusion of the motor disabled people. Chapter 3 details the initial user study that has been conducted in order to know the requirements and needs of wheelchair users based on their physical disabilities. Chapter 4 details the system design for each category of wheelchair users along with the interaction method. Next, we detail RFID based Smart Spaces in Chapter 5. System implementations for different categories of motor disabled people are described in Chapters 6, 7 and 8 along with the implemented use cases. Finally, a preliminary system evaluation for different categories of motor disabled people are described in Chapter 9 and Chapter 10 concludes the dissertation and points to future directions.

Chapter 2

LITERATURE REVIEW

Gray et al. [Gray et al., 2006] stated that social policies, conceptual models and classification systems have embraced the idea that disability is manifested when person environment interactions result in low or no participation in major life activities. In particular, we focus on the mobility disability, defined by individuals ability to move effectively in their surroundings, which predicts the onset of disability in tasks essential to living independently in the community and caring for oneself [Fried et al., 2000]. Researchers and practitioners are working to improve the social inclusion of wheelchair users by means of different technology advancements.

2.1 Wheelchair Advancements

Researchers and practitioners are trying to liberate the motor disabled people from dependency. They are working on the improvements of wheelchairs by enabling them with high tech resources and providing solutions to improve the social inclusion of wheelchair users. The research community is working to facilitate the interaction between physically impaired people and the surrounding environment, and to grant universal accessibility to information [Newell, 2008]. In fact, numerous work has been done to make infrastructural solutions for systems that can monitor and help people with physical disabilities [Stefanov et al., 2004].

Authors of [Kuno et al., 2000] propose an intelligent wheelchair that can be controlled by gestures. The authors claim that the number of wheelchair users are increasing and there should be advances by technology means in order to provide them a sense of autonomy.

This paper shows a guidance system for an electrical wheelchair for physically disabled people by head movements. A color face tracking system has been developed in order to compute head movements of the user and, depending on them, some commands are generated to drive the wheelchair [Bergasa et al., 1999].

The Shopping Assistant with interface for wheelchair users presents a use case to help wheelchair users shop independently without the assistance of others. The system proposed an extra cylindrical basket that can be lined with the normal shopping bags for easy transport of goods. It allows wheelchair shoppers to remain on the wheelchairs while shopping [Bremer et al., 2011].

Robotic system offers increased control functionality for the disabled users. Practitioners have developed a robot that consists of an electric wheelchair, containing robotic arm [Kumar et al., 2013]. A robotic arm that allows the user to autonomously collect a desired object from a shelf has also been developed. The object's position uses stereoscopic vision, from a camera placed on the shoulder of the user [Tsui et al., 2011]. Although it is an interesting work, it lacks of a practical approach consuming high resources and making it impossible for a wheelchair user to employ it in a practical life.

2.2 Interaction Methods for Wheelchair Users

Motor disabled people find standard computer input devices such as keyboard and mouse, difficult to use due to their disability. A number of keyboards and mouse configuration options designed to overcome physical difficulties exist [Trewin and Pain, 1999].

Most work on the usability of touchscreen interaction for people with motor impairments has focused on lab studies with relatively few participants and small cross sections of the population. To develop a richer characterization of use, authors have turned to a previously untapped source of data:YouTube videos. They collected and analyzed 187 noncommercial videos uploaded to YouTube that depicted a person with a physical disability interacting with a mainstream mobile touchscreen device. They coded the videos along a range of dimensions to characterize the interaction, the challenges encountered, and the adaptations being adopted in daily use. To complement the video data, they also invited the video uploaders to complete a survey on their ongoing use of touchscreen technology. Their findings show that, while many people with motor impairments find these devices empowering, accessibility issues still exist. In addition to providing implications for more accessible touchscreen design, authors reflect on the application of user generated content to study user interface design [Anthony et al., 2013].

Authors of [Kane et al., 2009] argue that mobile devices provide people with disabilities new opportunities to act independently in the world. However, these empowering devices have their own accessibility challenges. They present a formative study that examines how people with visual and motor disabilities select, adapt, and use mobile devices in their daily lives. They interviewed 20 participants with visual and motor disabilities and asked about their current use of mobile devices, including how they select them, how they use them while away from home, and how they adapt to accessibility challenges when on the go. Following the interviews, 19 participants completed a diary study in which they recorded their experiences using mobile devices for one week. Their results show that people with visual and motor disabilities use a variety of strategies to adapt inaccessible mobile devices and successfully use them to perform everyday tasks and navigate independently. They provide guidelines for more accessible and empowering mobile device design.

The purpose of this thesis was to investigate whether multimodal interfaces offer advantages in enhancing wheelchair users experience with communication and entertainment applications [Pires et al., 2010b]. This was achieved by studying alternative methods of human computer interaction, encompassing multiple input and output interaction modalities, specially targeted for motor disabled people. A user study was made in order to study their limitations with current software and hardware interfaces, regarding services like, email, agenda, conference and audio-visual information access (media center). After that study, guidelines and alternatives were proposed, based on a clear set of user requirements, and based on that, a multimodal prototype was made to verify or not those assumptions. One way to overcome physical disabilities consists on adopting other HCI modalities, such as if a user has difficulties on using her hands, she could opt to use speech instead. But by making a modality available, interaction simply does not improve. As it is evident that some modalities may not work properly on some environments or conditions, or simply their adoption does not make a user autonomous, as they could rely on using external devices that had to be configured by someone else. Multimodal systems improve interaction, by making various modalities available, a user can choose the best for him or for any situation.

Researchers and practitioners are trying to liberate the motor disabled people from dependency. Proence et al. [Ricardo Proença, 2013] presents a system allowing wheelchair occupants to get access to certain objects present in their vicinity by using computer vision techniques and pattern recognition. While this work presents an interesting system and an scenario intended to improve wheelchair users independence, it does not adapt well to retail and shopping scenarios where many similar products are present, and quick stock in stock out changing products becomes impossible to identify with the computer vision techniques. [Biswas and Langdon, 2012] the authors categorize the wheelchair users into different categories based on their hand strength, evaluating different kinds of interfaces. According to the study, touch screen interfaces scores higher than other interfaces with regard to usability. Research in [Chib and Jiang, 2014] shows a greater degree of mobility, sense of control, and opportunities to escape the stigma of disability, thus challenging the boundaries between the able-bodied and the disabled. Mobile phone appropriation allowed the management of personal identities and social networks, leading to a sense of empowerment.

As the technology is advancing, research is getting focused on opportunistic interaction modalities and aim to eliminate the digital divide introduced by the obsolete design paradigms [Fu and Huang, 2007]. There are some specific disabilities that can prevent the individual from using common interfaces and computer peripherals. For instance, [Kim et al., 2010] presented a camera mouse system based on a visual face tracking technique that helps users to interact with personal computers through head and face gestures. An interesting wearable system that can be used by wheelchair users having severe disabilities including hand or arm mobility has been presented in [Raytchev et al., 2009]. The system is based on a magnetic tracer for the tongue gestures recognition to control their surrounding environment. The authors of [Sato et al., 2009] developed a head gesture controlled electric wheelchair and in [Ling, 2004] the same wheelchair is controlled through shoulders gestures. The work is more focused on the development of technology enabled wheelchairs but no valid or practical approach is provided to interact with the items present in the surroundings of the wheelchair occupant.

An interesting work has been presented by Caon el al. that proposed different interacting possibilities for wheelchair users through gestures and Smart Phone. Authors used natural interaction possibilities and latest available technologies that makes it feasible approach. For the gesture recognition authors employed Kinnect camera [Caon et al., 2012].

Chib and Jiang shows how to achieve a greater degree of mobility, a sense of control, and opportunities to escape the stigma of disability, thus challenging the boundaries between the able-bodied and the disabled. Mobile phone appropriation allowed the management of personal identities and social networks, leading to a sense of empowerment, similarly by shopping independently that has been proposed in our research will lead towards more empowerment and bridge a gap between able-bodied and the disabled [Chib and Jiang, 2014].

Some works focused on specific accessible design for Smart Phones, as in [Verstockt et al., 2009] and [Tan, 2011]. Guesgen and Kessell demonstrated that gesture interfaces can help physically disabled people to make use of household appliances by gesture [Guesgen and Kessell, 2012] [Guesgen and Kessell, 2012] have presented Authors of the following article presents how deictic (pointing) gesture is of special interest in the interaction with smart environments and for people with motor disabilities [Karam, 2006].

Pires et al. [Pires et al., 2010a] studies different interaction models depending on the physical condition of the wheelchair users. Authors have studied touch screen interfaces along with Smart Phone interfaces and recommends best practices.

Authors of [Kane et al., 2009] study and present the outcome of mobile device adoption among motor disabled people. Authors have encouraged the usage of mobile devices for motor disabled people based on their study findings.

In April 2013 Washington University in St. Louis in collaboration with Missouri Spinal Cord Injuries Research Program have done a project called Terrain Tracker. The long-term goal of the Terrain Tracker project was to establish a method for rapid, large-scale usability reporting to identify and map usable spaces and businesses in communities that support the participation of people who use mobility devices. The short term goal was to determine touchscreen software application (app) features that are important to individuals with limited hand and finger function (LHFF) and to incorporate those features into the development of an app that allows individuals who use mobility devices to create and view web-based user reports of usability levels in a community [Garrett et al., 2013]. The results recommend best practices for user interface design when the end users are people with motor disabilities.

2.3 RFID and Wheelchair Users

While the authors of previous work present an interesting system and scenario in order to liberate wheelchair users from dependency, it does not provide a sufficient application in terms of retail and shopping where many similar stock in/ stock out products become impossible to identify with computer vision techniques.

Radio Frequency Identification (RFID) is becoming an essential part of retail industry because of the properties it provides such as automated stock count, localization anti-theft, etc. The tags contain item-based electronically stored identification. Unlike a bar code, the tag does not necessarily need to be within the line of sight of the reader, and may be embedded in the tracked object. RFID provides advantages over computer vision since it can identify individual items without direct line of sight, as well as hidden products. Similar products with little or no difference in their look can also be identified and tracked by RFID, for example clothes with same color but with different sizes or identical products but with different expiration dates. In addition to the increasing commerce value of the RFID market, many researchers in different domains have exploited RFID technology in recent years.

RFID technology has also been applied in other domains [Chen, 2012]. Since 2009, two credit-card companies have developed specialized microSD memory cards with RFID modules which embed a passive tag and an RFID reader. Mobile payment can be achieved after inserting the memory card in users' mobile phone[ban, 2009]. [Välkkynen et al., 2006] Evaluating touching and pointing with a mobile terminal for physical browsing enables physical browsing via mobile phone. The built system supports browsing concepts like selecting objects for interaction by touching and pointing at them. Their physical browsing system emulates passive sensor-equipped long-range RFID tags and a mobile terminal equipped with an RFID reader.

Considering the state of the art, we employ technologies that are readily available and commonly used in retail and in our daily life. We propose to take advantage of RFID that has already became a major player in retail industry along with Smart Phone, Heads-Up Display (HUD) and Touch Screen. Researchers have shown that the use of commonly used technology can help the disabled people to escape stigma [Sabelman and Lam, 2015] [McNaney et al., 2014]. We can provide a valid and practical solution to wheelchair users to shop independently and autonomously with minimal resources.

We presented a valid approach for wheelchair users to interact with the items on the shelf using RFID, Smart Glass and Smart Phone. We argued that a browsing, a concept usually reserved for the on-line world, consists in a sequence of media consumptions and clicks: reading text, looking at images, watching videos, interlaced with clicks that take us from one content to another. A similar concept does not yet fully exist in the physical world. In this paper we presented a system that uses Radio Frequency Identification (RFID) to obtain information about the objects on a shelf, and Augmented Reality (AR) to let users click on a live image of that shelf shown on a handheld device, accessing the information about the objects located in the vicinity of the clicked spot. A smart shelf with RFID has been set up to which a AR marker has been added to be able to map physical to screen coordinates. Testing and validation of system is done with different number of books at different locations on a shelf. The resulting experience is close to browsing a shelf, clicking on it and obtaining information about the objects it contains [Rashid et al., 2014a].

In our work we claimed that we are so used to surfing the web, clicking on links and getting instant feedback, that we often wonder why we cannot do the same on physical surfaces. We have coined *Crick* as a portmanteau term blending click and brick (and mortar) to describe the action of selecting a point on a physical surface with the purpose of receiving digital information about its content. In this paper we presented a browsable physical space with clicking solution. Our target space is a shelf equipped with Radio Frequency Identification (RFID) containing changing number of DVDs and books. The mouse is replaced by a Smart Phone acting as a touch pad, the cursor is replaced by a controllable moving head beam light that projects a spot on the shelf and the information about the products near the cursor’s position is then shown on a Heads-Up Display (HUD) such as Google Glass. The items can be localized and visualized at HUD with an accuracy of 99%. The system is developed in context to independent living i.e. wheelchair users [Rashid et al., 2014b].

Research on technology for wheelchair users is more focused on enhancing the capabilities of wheelchairs and empowering wheelchairs with more technology, rather than to enhance more participation of the people with motor disabilities in the society and giving them access to services like shopping, browsing etc. Research, in particular, is focused on accessing particular spaces and venues but lacks interaction possibilities with the surrounding environment objects. In this research we identified the open problem of interacting with the items present beyond arm length reach of wheelchair users. We aim to increase the interaction possibilities with the items present on the shelves, particularly in retail scenarios. In our approach we employed technologies that are readily available and commonly used in retail and in our daily life. We propose to take advantage of RFID that has already become a major player in retail industry and with minimal resources we can provide a valid and practical solution to wheelchair users to shop independently and autonomously. Particularly the solution we propose is for all the categories of motor disabled people having different degrees of disability. Our solution requires minimal resources and less infrastructural changes as compared to previous research related to the wheelchair users.

Biswas and Langdon categorizes the wheelchair users into different categories based on their hand strength [Biswas and Langdon, 2012], and evaluate different kind of interfaces. We considered all the categories (categories will be explained in next Chapter) of wheelchair users and propose a set of interfaces viable for each category.

In this research we propose the interaction solution for all the categories of wheelchair users based on different technologies collaborated with RFID. Our solution is based on the already adapted technologies by the society i.e. Smart Phone, Smart Glass etc. By providing a solution with already adapted technologies, will help to cope with the stigma of being separated from general public [Chib and Jiang, 2014].

Chapter 3

USER STUDY ON MOTOR DISABLED PEOPLE

Our goal is to improve independence and personal autonomy of motor disabled people by allowing them to shop independently in the stores. Our objective includes finding the product in the store, moving easily inside the store and interacting with the products present on the shelves outside arm length reach. In order to understand the specific motor disabled people needs regarding their shopping activities, a pre-study has been conducted in order to examine the potential usage of technology and interfaces by the people with motor disabilities. Details of the study are given below:

3.1 Categorization of Wheelchair Users

Although allowing wheelchair users to perform everyday activities is a basic requirement, the specific needs and features of independent shopping shall be rigorously defined, in order to find the optimal technological solutions. To achieve this goal we requested the participation of 9 volunteers from a non profit social solidarity organization for people with motor disabilities, which is partnering this research in Barcelona, Spain [Res, 2015] plus 9 other wheelchair users. With an average age of 45, participants had different degrees of impairment, as detailed in Table 3.1. Since hand mobility is key to interaction, we classify the users regarding their hand ability [Kurniawan, 2007] [Biswas and Langdon, 2012]:

- *H1*: Regular hand and arm mobility.
- *H2*: Low hand/fingers movements.
- *H3*: Severe impairment with no (or almost none) hand or finger mobility.

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

3.2 Analysis Method

Each volunteer was interviewed regarding their daily activities, assistance requirement and technology acceptability. The purpose of the interview was to analyze the subject condition and requirements with respect to shopping and technology acceptability. Inductive content analysis is used in this evaluation [Elo and Kyngäs, 2008]. The open ended questions that were asked include:

1. Do you usually go shopping (clothes, books, etc...)? (not online)
2. In affirmative case, briefly explain your experience in the store?
3. Do you shop alone, or do you need assistance (relative, friend, shopping assistant)? In which tasks do you need assistance?
4. How do you imagine technology (i.e. Smart Phone) could help you in the shopping process in a store?
5. Do you buy online? Why or why not?
6. Are you a regular user of libraries?
7. Do you need assistance in a library (from a relative, friend, librarian)? In which tasks within the library do you need assistance?

Moreover, users were given a comment section to write further about the problems and their feelings while shopping, and interacting with people (i.e. shopping assistants) for help and development in the society.

3.3 User Study Findings

- 16 out of 18 subjects reported their need for assistance in case of shopping or browsing.
- *H1* (8 participants) declared themselves as usual shoppers, while *H2* and *H3* (10 participants) went shopping occasionally or rarely.
- *H2* and *H3* participants coincide in their embarrassment when trying to communicate with store's staff due to their communication problems, leading to an unsatisfactory experience.
- Independence and privacy are the most required shopping features, and technology acceptability increases if these features can be provided.

Next, we will summarize the responses of subject 1 (S1) and subject 2 (S2). S1 response to question ”Do you usually go shopping(clothes, books, etc...)? (not online)” was:
I can't move with the wheelchair because there are a lot of people and not enough space (in a store, market, etc...). Moreover I need somebody assisting me, and most of the times they don't want to assist me because of my communication problems.

S2 response was:
I don't like to go shopping because I don't like anybody to help me shopping. I would prefer to do it alone..

S1 response to experience in the store was:
I have problems to take objects, not even take the money to pay. I also have vision problems, so I can't see small letters.

S1 response regarding the acceptability of technology assistance was:
An automatic payment system, without the need to take the wallet out. Also, a

Table 3.1: Motor Disabled Participants Description

Subject	Gender	Age Group	Severity Level	Shopping	Technology Acceptability
1	Female	26 - 35	H1	Usually	Yes
2	Male	26 - 35	H1	Rarely	Yes
3	Female	36 - 45	H2	Rarely	Yes
4	Female	36 - 45	H1	Usually	Yes
5	Male	36 - 45	H2	Rarely	Yes
6	Male	36 - 45	H1	Usually	Yes
7	Male	36 - 45	H1	Usually	Yes
8	Male	36 - 45	H1	Rarely	Yes
9	Female	46 - 55	H2	Rarely	No
10	Female	46 - 55	H2	Rarely	Yes
11	Male	46 - 55	H2	Rarely	Yes
12	Male	46 - 55	H2	Rarely	Yes
13	Male	46 - 55	H1	Usually	Yes
14	Male	46 - 55	H3	Rarely	Yes
15	Male	46 - 55	H3	Rarely	Yes
16	Female	56 - 65	H2	Rarely	Yes
17	Female	56 - 65	H3	Rarely	No
18	Male	56 - 65	H3	Rarely	No

big screen in the store entrance showing what's in the store and where.

To the same question S2 said:
A big screen in the store entrance showing what's in the store and where, with big pictures and big letters.

When asked about whether do they buy online? Why or why not? S1 answered:
No, because I don't have credit card. I also do not rely on giving my data on Internet.

S2 answered:
I do not rely on giving my data on Internet. It is interesting to mention the case of

S9, who is interested in shopping but do not want to take any kind of assistance from technology as she does not like technology.

Considering the responses of the subjects we concluded the study in shaping the shopping behavior of wheelchair users into three core points which are summarized next:

Independence and Autonomy. Wheelchair users do not feel comfortable to ask for help all the time during shopping or other public activities (like visiting a library), they feel ashamed and shy of taking assistance all the time. Not only because of the mobility issues, but also because their impairments sometimes also affect their communication capabilities, being difficult to understand for those not used. This increases the sense of deprivation and lower their self esteem. So they prefer not to go shopping in places where they always need assistance from others.

Technology Acceptability. Wheelchair users prefer to use technology means in order to obtain independence and have their own privacy. They want to improve their quality of life by adapting to technology.

Feel, touch and realism. Wheelchair users want to go to the store and physical places, like the rest of people, they like to see, touch and feel the items by themselves in order to enhance their shopping experience.

It is worth to mention the responses of two of the wheelchair participants here, when asked about the system necessity:

S7, said,
I do not like asking for help to anyone, unless strictly necessary, such as climbing stairs, or a high curb, etc. On the other hand, I am very traditional, and I like to enter the store, and to look at the products live and physically. I would like to adapt to technology as an opportunity to be more independent.

S10, mentioned,
We need some system, because for day-to-day activities, and all purchases done by wheelchair users, technology will help us shop by ourselves in any store, with-

out needing help and would help in gaining personal autonomy.

For wheelchair users it is a lot of effort to enter inside the shop or library in order to know the availability of an item and its location. For them it is worth to get the item information before entering. i.e whether the item is present or not, and if present which location of the store it is present. The conclusion of the study was that the wheelchair users need a technology-enabled system helping them in shopping and browsing independently, in an autonomous manner. They prefer to visit physical stores rather than shopping online and want to experience the physical shopping environment, like the rest of users.

Chapter 4

SYSTEM DESIGN BASED ON INITIAL USER STUDY

The knowledge obtained through the initial user study, is used in this chapter to design and implement a set of technologies specifically adapted to the requirements of each group of participants. An RFID-enabled shelf provides real-time inventory and location, while different interfaces adapt to each group of participants depending on their hand mobility degree. The interaction between the different components of the system is shown in Figure 4.2. We can divide the system into input methods and output methods.

4.0.1 Smart Space based on RFID System

Wheelchair users benefit from further information about the products in a store, like its availability and location, as extracted from the initial user study conclusions. Hence, a Smart Space technology providing such information on the items in the store is required. We propose the utilization of Ultra High Frequency Electronic Product Code Class 1 Generation 2 (EPC Gen2 for short) RFID [EPC, 2013]. An RFID system is composed of electronic tags (attached to objects), a reader or interrogator and an Information System (IS) managing the system's operations. This low-cost identification technology is the ”*de facto*” standard in retail since tags are passively powered (no battery required), are cheap (under 10 cents of dollar) and provide item-level identification.

In our work [Rashid et al., 2014b], we implemented a Smart Space pilot by

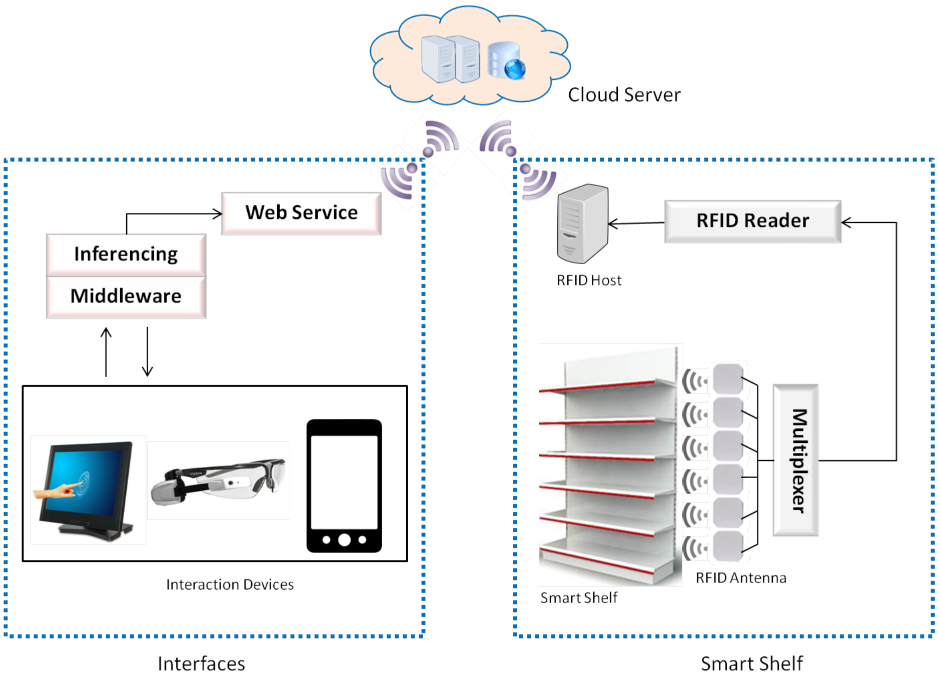

Figure 4.1: System Overview

enabling RFID on a regular shelf with books and DVDs reproducing the scenario. The resulting system provided the inventory every minute with over 99% accuracy (less than 1 in a 100 objects missed), and a space resolution of ∼25cm thanks to antenna multiplexing. RFID tags of different models from different manufacturers were attached to each product. A database within the IS stores information about each item including EPC (i.e. ID code), an image (i.e. cover) and all available information on the package. An inventory list, consisting of all objects' EPCs, together with their approximate locations is periodically uploaded to the database from the RFID system. Overall System Overview is shown in Figure 4.1.

Moreover, a check-in Touch Screen is placed at the entrance of the pilot room, simulating the entrance of a store. The screen is connected to the IS and has access to real-time information about real-time inventory, location (i.e. specific shelf), and products' information. This element solves the requirement of

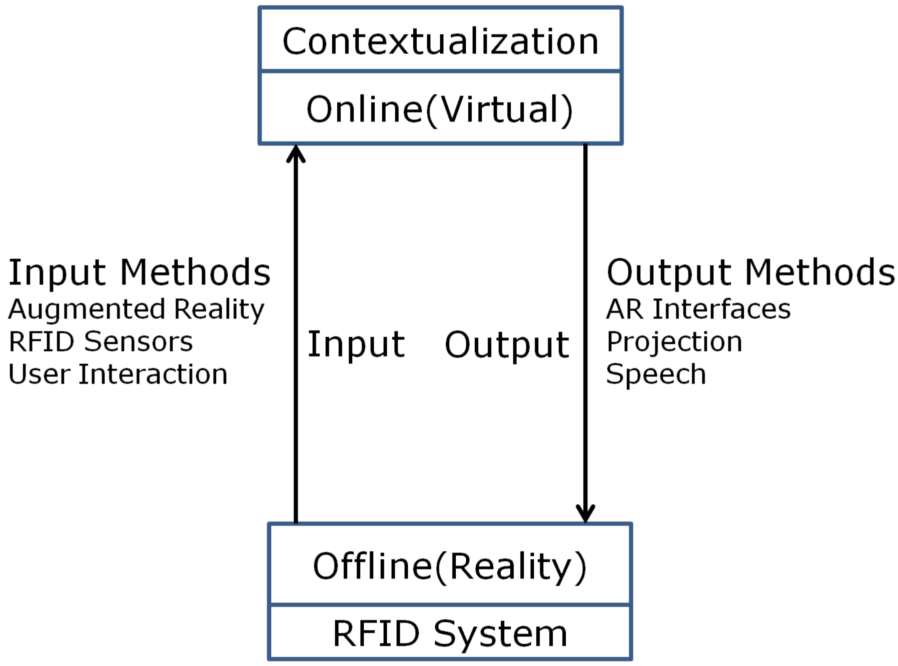

Figure 4.2: Components of the Proposed System

all groups of users to have information about product availability without the burden of moving inside the store to end up finding that the required product is sold out. The interaction use cases are designed to allow product selection, information extraction, location, browsing and purchasing. Since users may not reach the desired product, item retrieval will be performed by the store staff, and picked up at check out.

The following interaction methodologies are designed to allow product selection, information extraction, location, browsing and purchasing. Since users may not reach the desired product, item retrieval performed by the store staff, and picked up at check out. Moreover *H1* category can use *H2* and *H3* proposed system, and *H2* can use *H3* category proposed system. The user interface design process follows best practices for each category of motor disabled people [Biswas and Langdon, 2012], [Caon et al., 2012], and [Pires et al., 2010a]. We designed the interfaces and selected devices that are used by both able-bodied and disabled in order to avoid stigma of alienation by wheelchair users

[Chib and Jiang, 2014, McNaney et al., 2014]. Proposed interfaces can also be used for bridging online and offline worlds by both able-bodied and disabled [Pous et al., 2013].

4.0.2 Interaction Method for *H1* Category

Motor disabled people classified under the *H1* category have regular hand movement. This is the less restrictive group of users, since they have full hand mobility, but cannot reach certain objects without the assistance of another person (i.e. because of using a wheelchair).

Based on the output obtained in the Initial User Study (cf. Chapter 3) the utilization of Smart Phones or Tablets, together with AR, to access information about products on the shelves is proposed. The user point her device to the shelf, where an AR marker has been placed in the central part, thus knowing the approximate dimensions of the shelf on the screen. Moreover, the Hand-held device is connected to the Smart Space IS obtaining real-time information about the products on the given shelf, and its location within the shelf. On one hand, these devices are nowadays ubiquitous, so privacy is achieved by using their own devices. On the other hand, by pointing to an specific point in the screen, the system returns the items in that area of the shelf, and a further click on a specific product returns all available information. Previous studies recommend the use of Smart Phone and Hand-held devices for wheelchair users [Chib and Jiang, 2014] [Kane et al., 2009].

4.0.3 Interaction Method for H2 Category

H2 category users have low hand mobility (i.e. hand shaking). Since, these users are generally unable to use a Smart Phone on their own, same solution as for *H1* group is not possible. Instead, we propose the utilization of a second Touch Screen next to the pilot Smart Shelf. Use of Touch Screen with big fonts and interfaces are recommended in the previous studies conducted on motor disabled people [Pires et al., 2011, Biswas and Langdon, 2012].

4.0.4 Interaction Method for *H3* Category

Users under *H3* category can only use their hands for a limited set of actions (i.e. drive their wheelchair), and generally face severe communication problems.

Hence, *H1* and *H2* solutions do not apply for this group. However, their willingness for accessing and using traditional stores is the same, as concluded from the initial user study.

Allowing the visualization of information about the items on the shelf with the minimum hand movement is the goal for this group of users. Heads-up display (HUD) with AR is proposed. The HUD detects the AR marker on the center of the shelf (also used by *H1* users), and shows information about the items on the screen of HUD (thanks to the updated RFID information). Once the desired item is shown on the HUD, a voice command or hand touch on the side of the HUD selects the item and displays the available information for the product. Studies have shown the acceptability of HUD by disabled people [McNaney et al., 2014].

Chapter 5

SMART SPACES BASED ON RIFD SYSTEM

Smart Spaces are created with the help of sensing technologies (i.e., location sensors, mobile sensors, and environmental sensors) and computational devices that are ubiquitous around us and pervasive in our environment. They support the true setup of ubiquitous computing without disturbing the user daily life ability to learn about their occupants. Collectively, it enables the environment to exchange the context with connected devices and possibly social exchanges. An extension of the connected devices is to provide the dynamic contextualization to include real objects on the basis of user interactions using augmented reality technologies.

Within the range of different RFID technologies, we used the Ultra High Frequency (UHF) Electronic Product Code Class 1 Generation 2 (EPC Gen2 for short) [EPC, 2013] in our system, since it is *de facto* standard in retail. It is a passive technology, meaning that electronic labels are battery less, and provides a 96-bit item-level identification. The identification range is up to 10 meters, but it is usually calibrated to a lower range (two to three meters) to avoid interference due to high signal power. In this way antenna-based localization is also improved, but it can also be improved by means of received signal strength indicator (RSSI) analysis.

Wheelchair users benefit from further information about the products in a store, like its availability and location, as extracted from the initial user study conclusions. Hence, a Smart Space technology providing such information on the items in the store is required. An RFID system is composed of electronic tags (attached to objects), a reader or interrogator and an Information System (IS) managing the systems' operations. This low cost identification technology is the "de facto" standard in retail since tags are passively powered (no battery required), are cheap (under 10 cents of dollar) and provide item level identification.

The RFID system produces a list of the Electronic Product Codes (EPC) of every items on the shelf, and its approximate location, and stores it in a local computer. The EPC is the common standard using to identify objects with RFID. In its most common format its a 96 bit number. Ultra High Frequency (UHF) RFID, defined in the Electronic Product Code Class 1 Gen2 (EPC Gen2) [EPC, 2013], is de facto standard in retail.

A database stores information about every possible items class (a.k.a. Stock-Keeping Unit - SKU), including their images. Every time a new object is added to the system, the EPC code of its RFID tag is added to the database, linking it to the particular product class. This way item information is normalized, stored only once per product class, even though many objects (product instances) of such product class are present. An inventory list, consisting of all the EPCs of the objects present on the shelf, together with their approximate locations is periodically uploaded to the database from the local computer of the RFID system called RFID host.

Next we will summarize different components of RFID system that includes RFID Reader, Antenna, Tag, Multiplexer.

5.1 Components of RFID System

5.1.1 RFID Reader

An RFID reader, also known as an interrogator, is a device that provides the connection between the tag data and the enterprise system software that needs the information. The reader communicates with tags that are within its field of operation, performing any number of tasks including simple continuous inventorying, filtering (searching for tags that meet certain criteria), writing (or encoding) to selected tags, etc.

Figure 5.1 shows a Keonn RFID reader [Keo, 2014]. The reader uses an attached antenna to capture data from tags. It then passes the data to a computer for processing. Just like RFID tags, there are many different sizes and types of RFID readers. Readers can be affixed in a stationary position in a store or factory, or integrated into a mobile device such as a portable, Hand-held scanner. Readers can also be embedded in electronic equipment or devices, and in vehicles.

Figure 5.1: RFID Reader

5.1.2 RFID Antenna

RFID readers and reader antennas work together to read tags. Reader antennas convert electrical current into electromagnetic waves that are then radiated into space where they can be received by a tag antenna and converted back to electrical current. Just like tag antennas, there is a large variety of reader antennas and optimal antenna selection varies according to the solution's specific application and environment [Keo, 2014]. Figure 5.2 shows a RFID antenna.

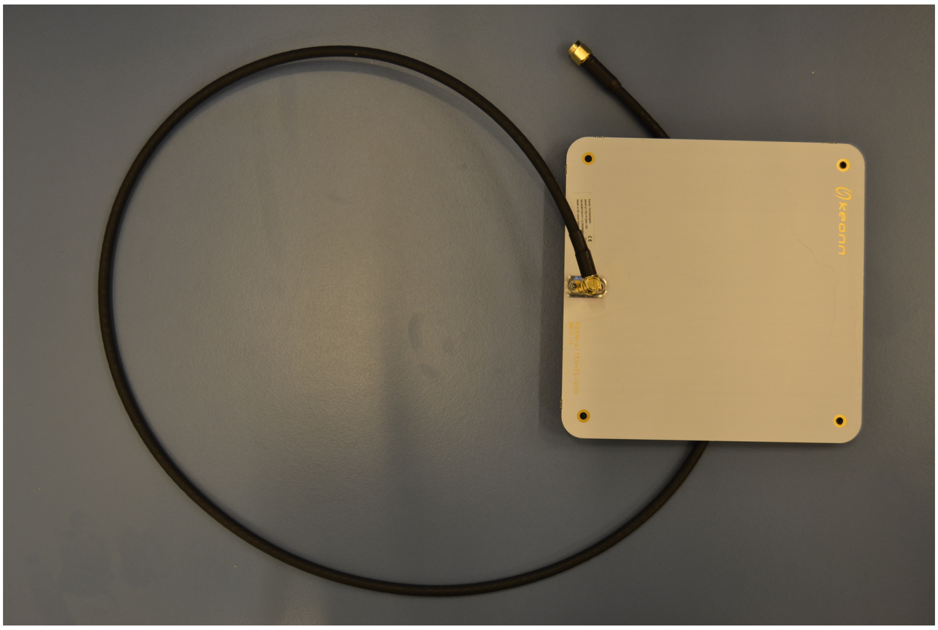

Figure 5.2: RFID Antenna

The two most common antenna types are linear and circular polarized antennas. Antennas that radiate linear electric fields have long ranges, and high levels of power that enable their signals to penetrate through different materials to read tags. Linear antennas are sensitive to tag orientation; depending on the tag angle or placement, linear antennas can have a difficult time reading tags. Conversely, antennas that radiate circular fields are less sensitive to orientation, but are not able to deliver as much power as linear antennas.

Choice of antenna is also determined by the distance between the RFID reader and the tags that it needs to read. This distance is called read range. Reader antennas operate in either a "near-field" (short range) or "far-field" (long range). In near-field applications, the read range is less than 30 cm and the antenna uses magnetic coupling so the reader and tag can transfer power. In near-field systems, the readability of the tags is not affected by the presence of dielectrics such as water and metal in the field. In far-field applications, the range between the tag and reader is greater than 30 cm and can be up to several tens of meters. Far field antennas utilize electromagnetic coupling and dielectrics can weaken communication between the reader and tags.

5.1.3 RFID Tag

Figure 5.3 shows a RFID tag. The tag's chip or integrated circuit (IC) delivers performance, memory and extended features to the tag. The chip is pre-programmed with a tag identifier (TID), a unique serial number assigned by the chip manufacturer, and includes a memory bank to store the items' unique tracking identifier (called an electronic product code or EPC). The electronic product code (EPC) stored in the tag chip's memory is written to the tag by an RFID printer and takes the form of a 96-bit string of data. The first eight bits are a header which identifies the version of the protocol. The next 28 bits identify the organization that manages the data for this tag; the organization number is assigned by the EPCglobal consortium. The next 24 bits are an object class, identifying the kind of product; the last 36 bits are a unique serial number for a particular tag. These last two fields are set by the organization that issued the tag. The total electronic product code number can be used as a key into a global database to uniquely identify that particular product.

5.1.4 RFID Multiplexer

Figure 5.4 shows a RFID multiplexer. In many cases when setting up an RFID system it is not desirable to connect each and every antenna directly to a reader as this might mean having to operate a very large number of readers. To reduce complexity and hardware costs for readers dramatically, the use of a multiplexer can make sense. A multiplexer is a switch that switches the antennas connected to the reader, allowing to connect up to 16 antennas to one reader. In cases in which reading an antenna e.g. every 500 milliseconds is enough this approach can save hardware costs for readers which are often the most expensive item in an RFID system.

5.2 RFID based Smart Shelf

To turn a shelf into an RFID Smart Shelf, a set of antennas must be placed on the shelf. Since there is no "a priori" information on where the items will be placed, the whole surface must be covered. The distance between antennas determines the accuracy of the location information. Antennas were placed every

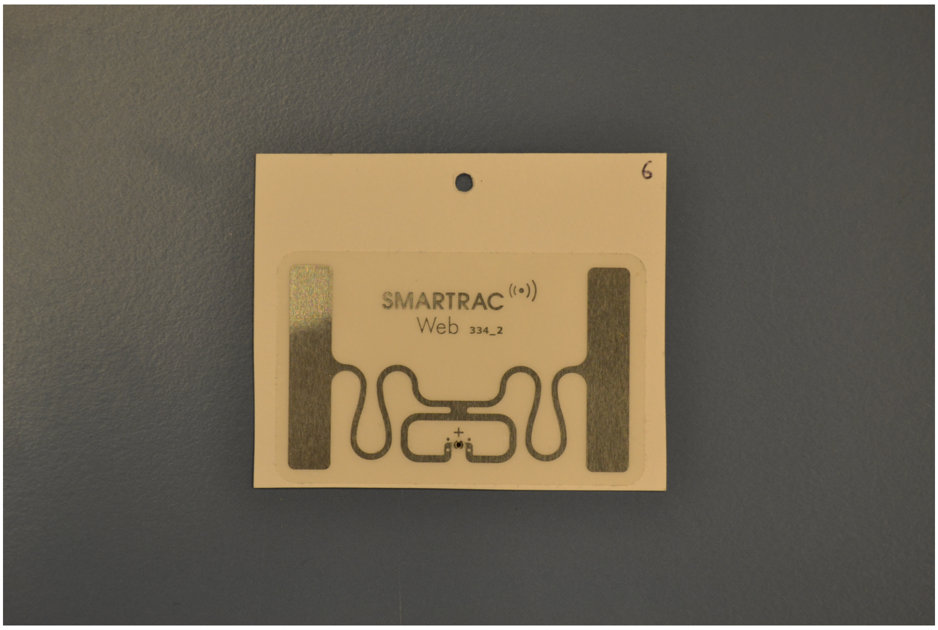

Figure 5.3: RFID Tag

25-30 cm in both vertical and horizontal directions. The shelves used had an approximate width of 100 cm and an approximate height of 200 cm, so 8 rows of 4 antennas were used. The antennas used were dependent on the shelf material. For wooden shelves the Advantenna-P11 from Keonn Technologies was used. For metallic shelves the Advantenna-S11 was used. The RFID reader was model AdvanReader-100 also from Keonn Technologies. Since the reader only has 4 antenna ports, 4 1-to-8 multiplexers AdvanMux-8 were used. The resulting system provided the inventory every minute with an accuracy better than 99% (less than 1 in a 100 objects missed), and a space resolution of ±25 cm. RFID tags of different models from different manufacturers were used, depending on the type of items. The front and back view of the Smart Shelf is shown in Figure 5.5. Figure 5.6 show a complete RFID enabled Smart Shelf along with RFID tagged product. All the RFID equipment used in this research are taken from Keonn Technologies S.L Barcelona, Spain [Keo, 2014].

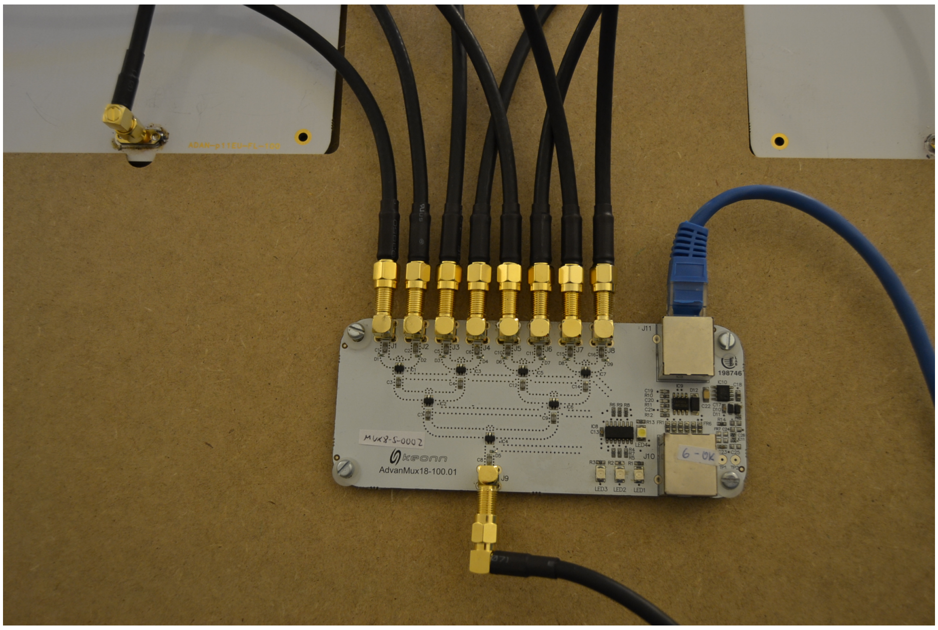

Figure 5.4: RFID Multiplexer

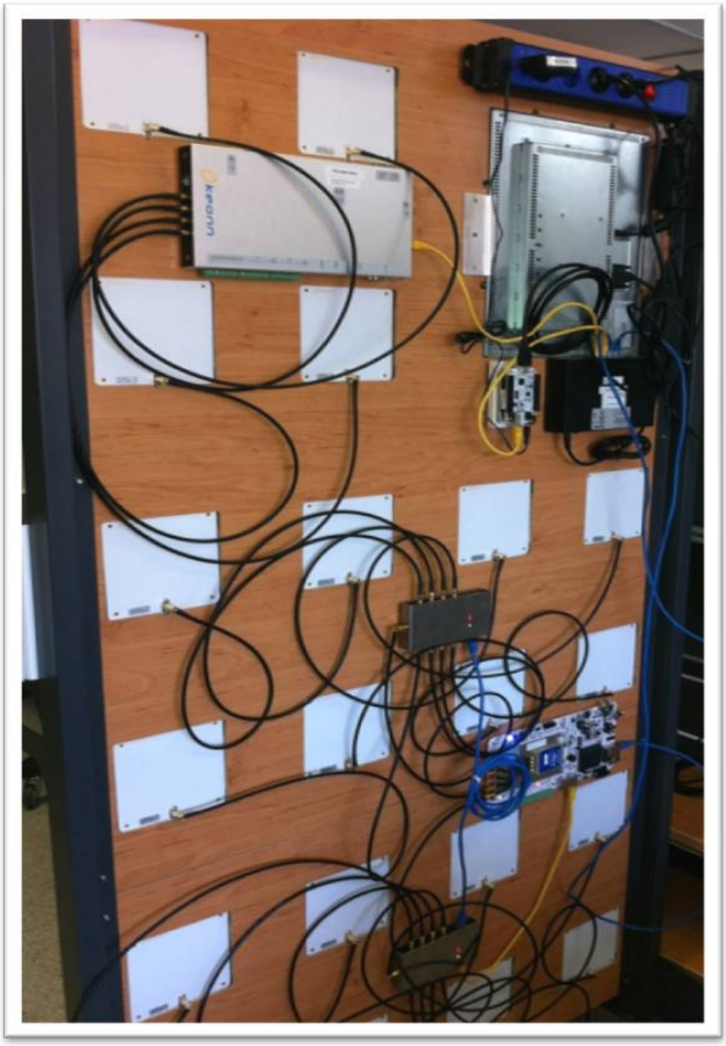

Figure 5.5: Back of a Wooden Smart Shelf Showing the RFID System.

Figure 5.6: A) Back of a Metallic Smart Shelf showing the RFID System. B) Frontal view of Shelf with RIFD tagged products. C) Product showing RFID Tag.

Chapter 6

H1 CATEGORY INTERACTION IMPLEMENTATION

In this chapter we will explain the interaction implementation and system for the *H1* category wheelchair users. The system allows the user to interact with physical items through AR interfaces that runs on Smart Phone or a Tablet referred also as Hand-held device. The user interaction with the items is also possible through a voice interface. Proposed project contributes towards the bridging of online and offline worlds. The user is able to switch quickly and flawlessly from the offline world to online and vice versa. Users can select, switch and browse the items in the same way as online browsing, in this way we can give more sense of control and immediate satisfaction by interacting digitally with physical spaces. To achieve this objective, we propose sub systems: an RFID-based Smart Shelf, and an augmented reality (AR) system using markers. The Smart Shelf is able to inventory and determine the approximate location of all the items, which have previously been labeled with an RFID tag. The AR system uses a AR marker to map the physical coordinates of the shelf to the screen coordinates of a Hand-held device showing a live image of the shelf. With these systems in place, the user is able to click on the image of the shelf on the Hand-held device, the coordinates of the click will be translated to coordinates on the shelf, a web service call will be made about which objects are in the vicinity of such coordinates, and information about those objects shows on the screen, superimposed in the appropriate position on the screen. When objects are added or removed from the shelf, or their location is changed, these events are automatically detected by the RFID system, so that the information provided to the user corresponds to the actual state of the shelf.

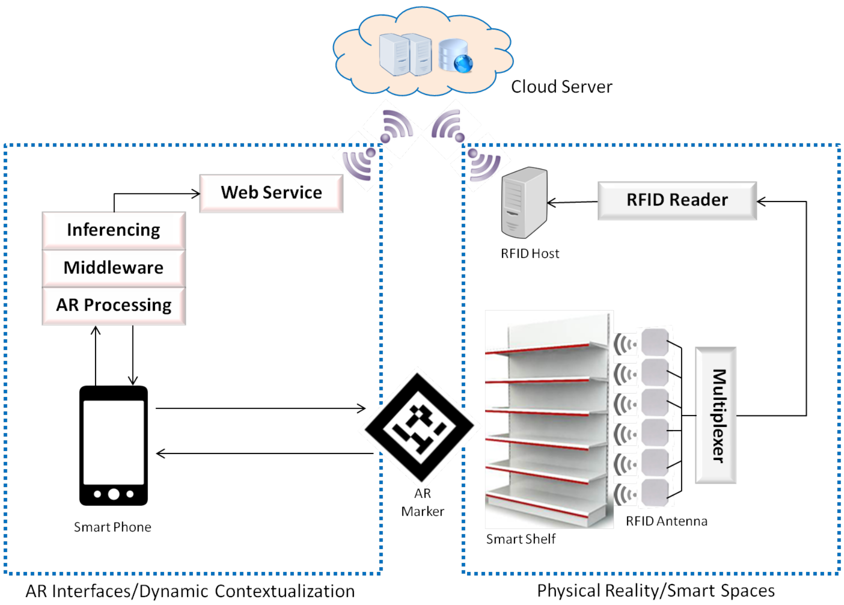

Figure 6.1: System Overview.

6.1 Augmented Reality System

The AR system is an application running on the Android Hand-held device. When the Hand-held is pointed to the shelf, it uses a AR marker placed on a known position of the shelf to determine the origin, scale and rotation of the shelf coordinates with respect to the screen coordinates. When a user clicks on the screen, the coordinates of the corresponding shelf position are calculated by the AR system. A web service obtains a list of all the EPC codes that the RFID system has reported as located within a certain distance of such shelf position. A further web service call obtains the information and images of those objects, which are shown by the AR system on the screen. An area of interest referred as green square superimposed on the shelf image indicates at all times the area about which the information is being shown. The AR system was developed as an Android application based on the Metaio SDK [AR-, 2010]. The cloud database was built using a Postgres DBMS. The AR system uses a AR marker, which is placed on the Smart Shelf and is used by the AR system to map the coordinate system of the physical shelf to the screen coordinates of the Hand-held device. This mapping includes a translation, a scaling, and a rotation. To maximize the accuracy of the mapping the marker was placed near the center of the shelf, where the mean distance to any point on the shelf is minimized. Also, for acceptable accuracy when a user was standing up to 150 cm away from the shelf, the marker must have a dimension of at least 8 cm on each side. The result of the mapping is that every time a user clicks on the screen, a pair of coordinates on the shelf are calculated. A green square is placed on the screen at the position where the user clicked, as a reminder of the chosen shelf position. As the user moves the device, the green square is moved on the screen, keeping it always on the same shelf position. For this, a continuous "reverse" mapping of shelf coordinates to screen coordinates is done. A web service returns the list of all objects which are reported by the RFID system to be within 25 cm of the calculated coordinates. Another web service call obtains all the information available about the objects, including the images. Since the items used are books, DVDs and CDs, the images of the set of items are presented with a "cover flow" interface at the bottom of the screen. This information is updated in real-time (with the time resolution of one minute set by the RFID system), and if an object is removed, added, or relocated, the change is updated on the screen. Since RFID technology does not require direct line of sight, information will be shown on the screen about all items in the area, including those hidden behind other items and not directly visible to the user.

6.2 System Work flow and Architecture

From the core architecture point of view the whole system is divided into three basic layers. The whole process is explained in Figure 6.2. The first layer is for the user interaction on the Hand-held devices, a friendly user interface is designed in which user is able to aim the Hand-held camera at the Smart Shelf with live video running on it and tap the specific area of interest. The user area of interest location is passed to the Metaio SDK which then maps the location to

Smart Space. Next, the location segmentation of the particular area of interest is performed. Once we get the specific segment, this information is passed for inferencing inside the middleware. During the dynamic inferencing process, the contextualization of the item is performed and then the output is passed to the third and last layer, that is the output layer. In the output layer an interactive AR interface allows user to view the particular information in real-time and browse items.

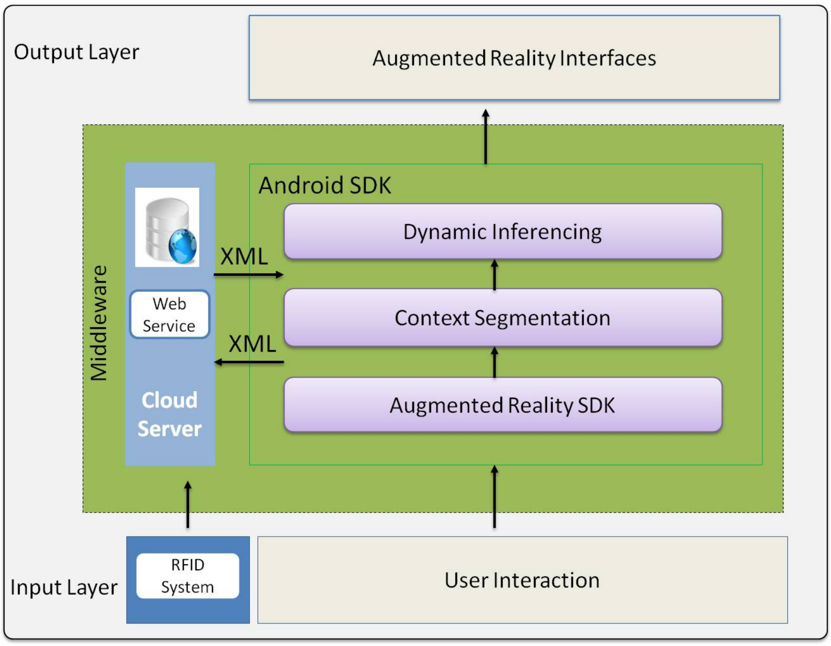

Figure 6.2: System Architecture.

The system is designed in such a way that all the use cases are available to the user in a single interface. User can search, browse or tap at particular point from the same interface. System work flow is shown in Figure 6.3. Once the user clicks at any the particular point on the screen of Hand-held device, the pixels of the user tapped position are retrieved and passed to Augmented Reality SDK in order to get X, Y and Z axis in 3D space i.e. shelf with respect to AR marker, then axis are translated with respect to the shelf origin. Once the exact location of user tapped point is translated to the corresponding point on the physical shelf, the items information at that location on the shelf are retrieved. After getting the relative item information, an AR interface is constructed for the items. Usually the item is shown in the form of cover flow images. Behind the scenes the RFID system is continuously inventorying and updating the locations of the items on the shelf. Similarly the browsing in horizontal and vertical direction, along with the search option is passed directly to the coordinate calculation module.

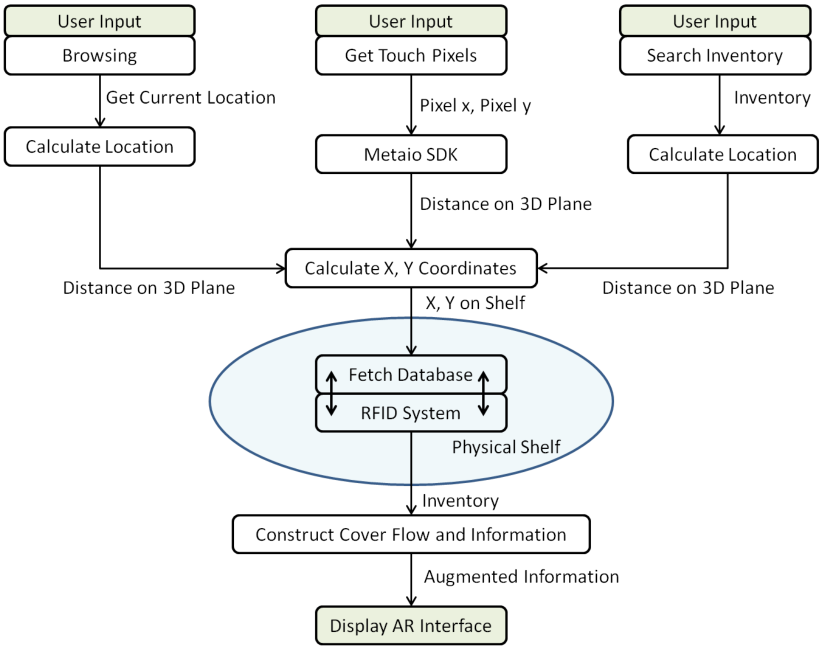

Figure 6.3: System Work Flow.

Shelf Segmentation

We have divided the complete shelf into segments based on the RFID accuracy, each shelf segment is 25*25 cm. All the items present withing this one segment will be regarded as one location. In order to move from one segment to another we have used formula as shown in below mentioned equations. The identification of different segments of shelf is done through transformation matrix and metaio SDK. m and n represent the different segments of the shelf and x and y represent the axis location while c is a constant representing RFID accuracy. 25 cm on the physical shelf scaled down to Hand-held devices with small screen in order to provide them enough room to browse among different segments.

$$m = floor\left[\frac{x}{c}\right] + 1 \tag{6.1}$$

$$n = floor\left[\frac{-y}{c}\right] + 1 \tag{6.2}$$

6.3 Augmented Reality Interfaces

The application implements four different use cases, all sharing the same infrastructure and, for the most part the same interface. All three use cases are available at all times, and they can be used in any sequence, an unlimited number of times. We have implemented *Cricking* by means of Mobile AR and RIFD. Users clicks on the screen of the Hand-held device and gets the information from the physical shelves with the help of RFID. AR and RFID in combination with each other providing the method to click on the physical space and gets the feedback i.e. *Cricking*

6.3.1 Browsing at a particular location

Figure 6.4 shows the browsing by clicking at a particular location. The user aims the camera of Hand-held device at the shelf so that the marker is visible on the screen. Then the user can click on any point on the image of the shelf on the screen. At that point a green square is placed at the click point, and the interactive images of the items are shown at the bottom of the screen. As the user moves the screen, the green square continues to point at the same shelf locations, even though this shelf location moves around the screen (as long as the marker continues to be visible). If the user clicks on an item image, the available item information is shown on the screen. If the contents of the shelf vary, these variations will be reflected on the information shown on the screen. If one of the items shown on the screen is removed from the shelf or moved to a different location, it will disappear from the screen. Conversely, if a new item is added to the location being examined, it will appear on the screen. The latency of this changes is determined by the one minute time resolution of the

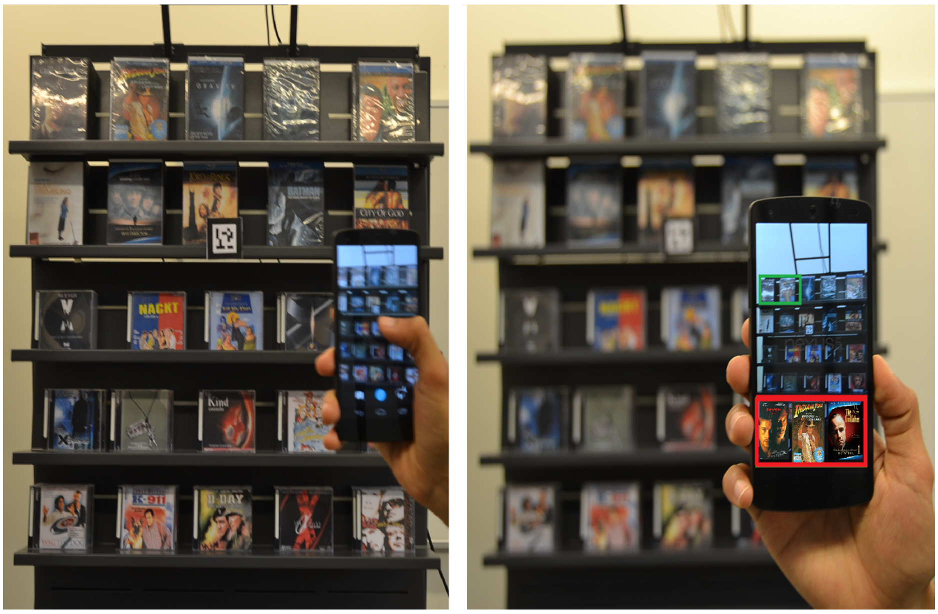

Figure 6.4: Hand-held device pointing at the Smart Shelf, where the AR marked is visible. Close up view of the Hand-held screen, showing the superimposed item information, and the green square indicating the active area i.e. the user clicked location.

RFID system. One minute time resolution depends upon the number of antennas connected and read time dedicated for each antenna. Figure 6.6 and 6.5 shows screens shots of the Hand-held AR interfaces.

6.3.2 Browsing around the shelf

Figure 7.4 shows the AR interface for navigation around the shelf. After the user has selected a location on the shelf and the information about the items on that location is shown on the screen, four arrows are available to navigate up, down, left or right. Clicking on any of these four arrows is equivalent to clicking on the screen on a position exactly 25 cm up, down, left or right with respect to the previous position.

The set of items found at that new location is shown, and the green square moves

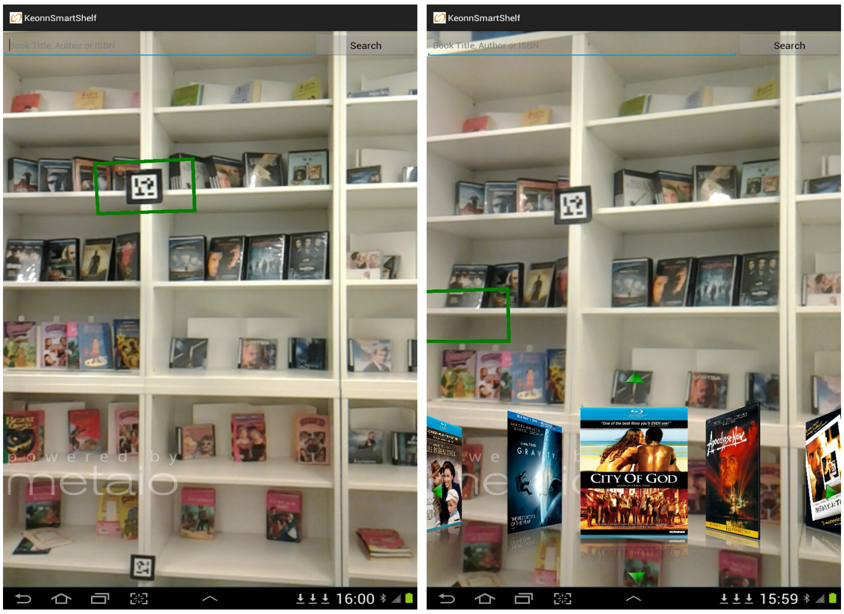

Figure 6.5: Screen Shot of Hand-held AR Application Showing Cover Flow Interfaces.

correspondingly to indicate the new active location. As before, any of the item images can be clicked to obtain the information about the item.

6.3.3 Search for a given item

At any time the user can use a search box to search for a given text string. All the items containing this string within any of the information fields in the database (e.g. title, author, description, etc.) will be listed (or an error message will be shown if no items match the search string). When the user selects one of them, the green square will move to the location where the selected item is found on the shelf, and the images of all the items found within 25 cm of that location will be shown at the bottom of the screen. From here the user can choose to see the information about any of the located items, can click on a different shelf position, or can browse around the shelf using any of the 4 arrows.

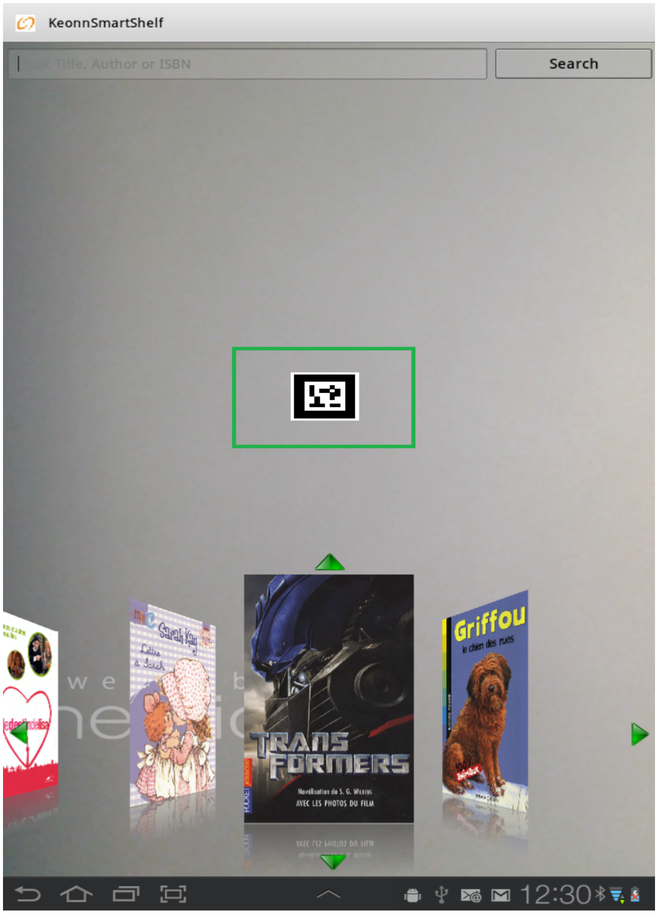

Figure 6.6: Screen Shot of Hand-held AR Application Showing all the use cases.

6.3.4 Retrieval of an item

All the time the user is provided with the add to list icon on the screen. With this icon user can make the list of items to be purchased, then order and can collect at the counter. The selected items list is constantly being updated at the counter section of the store in real-time. The user can call the shop assistance to retrieve browsed or selected items from the shelf in case of wheelchair user anytime, with the help of assistance icon. After browsing and making the list of

Figure 6.7: Navigate in Horizontal and Vertical Direction.

interested items, users are envisioned to use the retrieval functionality depending upon their need i.e. at counter or at the same time in front of the shelves.

6.4 General System Usage by Wheelchair User

It can be best explained in narrative form.
Wheelchair user Bob, 27, puts the Tablet on his lap and pushes his wheelchair to the Cinema section. The Hand-held device will be provided at the Smart Shop also (we referred the shops who have acquired this system as Smart Shops) in case the subject does not have one. Books about cinema have lots of pictures and are hard to browse on Amazon. He reaches his favorite shelf, full of large books, with shiny covers. Too bad he cannot reach most of them. He could ask someone to help him and get the books for him, but which ones. He cannot ask for every book! Normally, he would leave in frustration, but today he has technology on his side. He points the Tablet to the shelf, where he sees a live video image of the books in front of him. He click a particular part of the shelf on the Hand-held, and the images of 5 book covers appear, like floating on top

Figure 6.8: Search Results Shown with the Physical Location of the Item on the Shelf

of the live image. It is like the store knows what's on the shelf, and is letting Bob browse it with his finger on the screen. Bob now slides his finger over the image of the top shelf, and its contents appear on the screen. It's like he can reach up there, but he is still sitting on his wheelchair. Pointing to the screen, after all, he can do that at home. He came to feel the books in his hands. He picks up a book from the only shelf he can reach. It is a copy of Hitchcock on Hitchcock, a book he already owns. But somehow, the Tablet seems to know he has picked up this book, because the screen is showing the title, and three bright dots showing three specific locations on the shelf. Bob points his finger to one of them, and realizes that the augmented reality application is now showing him other books about Hitchcock. Apparently, a copy of Footsteps in the Fog: Alfred Hitchcock's San Francisco' is available three shelves above. On the same shelf, further to the right, there seems to be a copy of "Cinema by the Bay", not about Hitchcock, but popular among Hitchcock fans. Through a special icon on the *screen, he requests the assistance of a store clerk, and asks her to get these to books for him. Good choice, she says as she handles them to him. He spends twenty minutes with the books on his lap. Looking at the pictures, turning the pages, smelling the scent of old paper. He could get used to this. He continues strolling around the store, using the augmented reality interface on his Tablet to browse the whole store. Before he knows, an hour and a half has gone by. He is carrying three books, and a collector's DVD edition of "Vertigo". Finally he decides to buy two of the books and the DVD, and places the rejected book on the first shelf he can reach, which happens to be in the Biographies section. As he exits the stores he is thinking Goodbye Amazon, hello Augmented Reality.*

Chapter 7

H2 CATEGORY INTERACTION IMPLEMENTATION

In this chapter we focus on group *H2* for the further study. It is worth noting that *H1* users, as well as non-impaired users, can also use any solution designed for the *H2* group.

As described in the initial User Study (Chapter 3), users find difficult to get into stores, needing a lot of effort to move in the store. Moreover, the users do not know whether the particular product they are looking for is present or not. For that reason, one screen is planned to be placed at the entrance of the store to facilitate information about the presence of the product with the accurate location inside the store i.e. particular shelf. A second screen is planned to be placed near the shelf containing the item. As users have poor hand mobility, touch screens with large interface are used to facilitate users the interaction with the system. The use of touch screen with large fonts and interfaces is recommended in the previous studies conducted on the the motor disabled people [Carlos Galinho Pires, 2011]. In fact the touch screen interfaces are highly recommended over other interfaces like Smart Phones or Tablets because most of the wheelchair users can not manage them properly [Biswas and Langdon, 2012]. The proposed system is completed with an RFID-based Smart Shelf, with the two touch screens with web interfaces connected to the Smart Shelf. The RFID Smart Shelf provides real-time, accurate item location information, which is basic in stores where products may be placed in different and rotating positions.

7.1 Interactive Web Interfaces based on Smart Shelf

Since the users have poor hand mobility, big touch screens with web interfaces are used. Poor hand mobility implies shaking hand movement, being harder for the user to click at certain point precisely. Keeping in mind the user requirements, interfaces are designed with large fonts, buttons and big size images. Touch screens are also chosen since users cant grab a Smart Phone, Tablet or any Hand-held devices. Touch screens at stationary positions are chosen keeping in mind the user ability to interact. Interfaces are designed in HTML5 with JQUERY and JAVA Script. A database is accessed through web service which is periodically updated by the RFID system. Web interfaces provide real-time information of the products presence and location in the shelf and in the store thanks to the RFID real-time inventory update. In this scenario *Cricking* is implemented by means of combining Touch screen interfaces with RFID. By clicking on the Touch screen interface, user can get the real-time information of the products present on the physical shelves. Click on the Touch screen interfaces regarded as click on the physical shelf i.e. *Cricking*.

7.2 System Work flow and Architecture

The system work flow and architecture is shown in Figure 7.1. The overall system can be divided into three layers: two layers include the user interfaces and the third layer include the RFID system and interconnection with the system. All the use cases available to the user in the initial screen are connected to the database through web services. The RFID system is also connected to the same database. Once the user performs any action at the initial screen, it is recorded in the database. The second screen interface reflects the same change by connecting to the database through the web service. The web service implements different web methods for both the interface and the RFID system. Both the touch screens and RFID system are interconnected through the web service and database. The web service is programmed in Java and a MySQL database is used. For browsing inside the store, the interface invokes the *ShowItem* web method that queries database to retrieve all the products of particular category. Once the user selects some product and do add to cart, it invokes the *AddtoCart* web method to insert into the database that particular product item, then at the second screen interface show cart action invokes the *ShowCart* web method that queries database to retrieve particular product that user had selected. In this way all the different components and actions of the system collaborate and synchronize with each other. Apache Tomcat server is used for hosting the web service.

7.3 Implemented Use Cases

Considering the average shopping environment and merging it with the wheelchair users needs provided in Chapter 3, different use cases have been implemented and detailed in the following subsections. These use cases provide a complete life cycle for product browsing, selection and purchase.

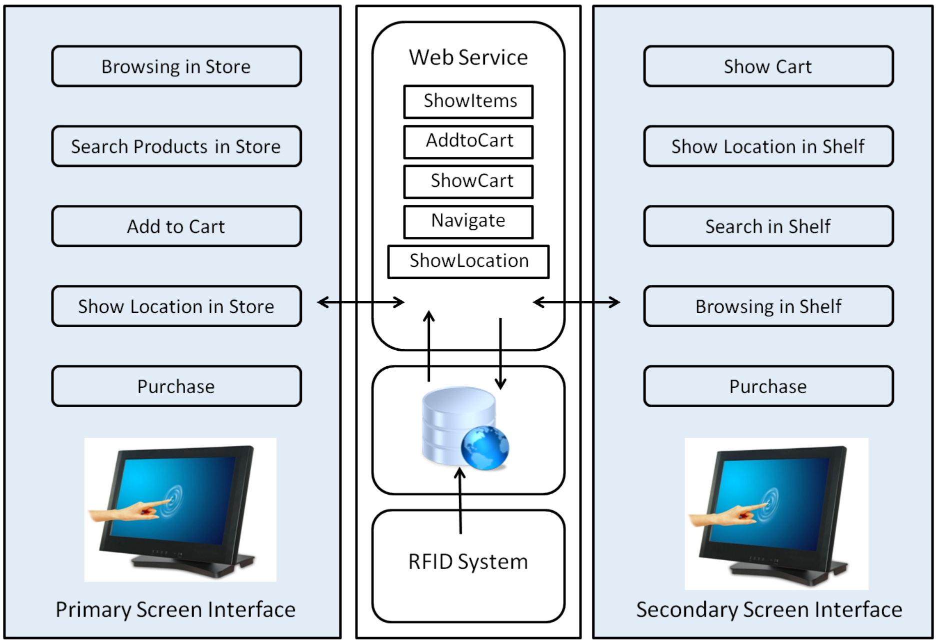

Figure 7.1: System Workflow and Architecture.

7.3.1 Looking for the product in the store

Figure 7.2 shows the initial screen interface. The initial screen interface (placed at the entrance of the store) provides to the user the overall information of the product presence and distribution among the different shelves inside the store. Users can browse through different products and their respective categories. Moreover, the users are given the option to select the product and make a list of selected products. After browsing through different products and selection of particular products, users are provided with the information of particular products and its location inside the store. Location of the shelf has be shown to the user on a map at the entrance of the store, which contains all the physical locations of the shelf placement inside the store, so wheelchair user can directly go that particular shelf. All the selected products are automatically added to the list of selected products, to be shown on the interface near the shelf screen (second interface). The available information by interacting the products are: category, price, comments and ratings.

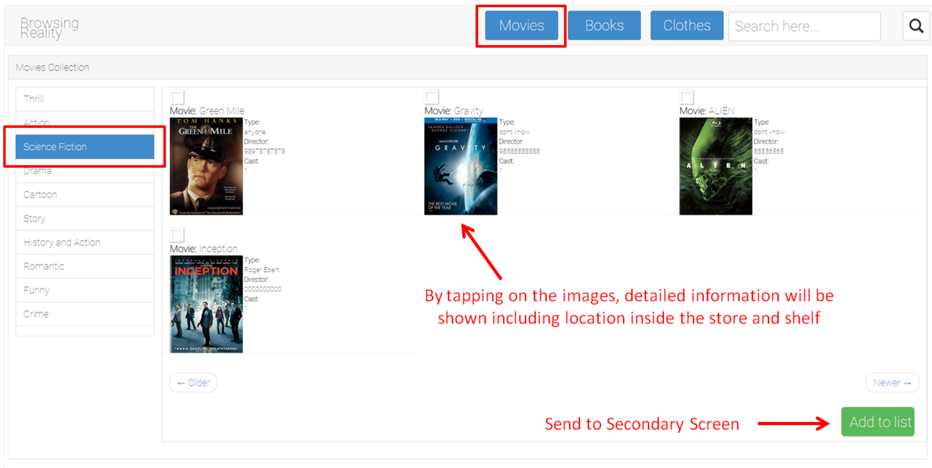

Figure 7.2: Initial Screen Interface.

7.3.2 Selected Product Information and buying

Figure 7.3 shows the second screen interface. Once the users have selected products from the initial screen, the products are automatically transferred to the second screen (close to the shelf). Users can then inquire about the selected products, or perform new queries. Users are provided with the exact location on the shelf, price, and other relevant information about the product inquired. If a user decides to buy the product, she can select it and it will be retrieved by a store assistant, and brought to the checkout counter section.

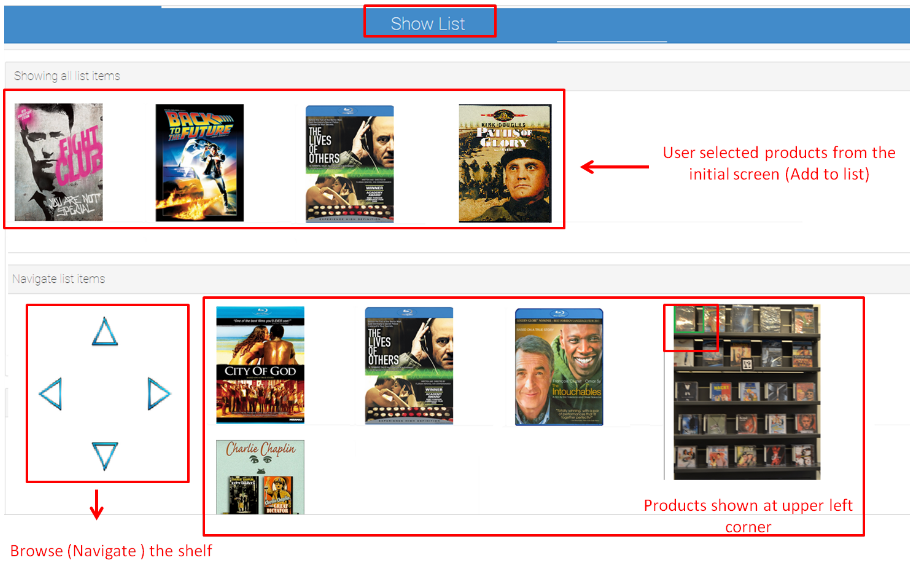

Figure 7.3: Second Screen Interface.

7.3.3 Browsing around the shelf

Figure 7.4 shows the web interface for navigation around the shelf. After the user has selected a location on the shelf and the information about the items on that location is shown on the screen, four arrows are available to navigate up, down, left or right. Clicking on any of these four arrows is equivalent to clicking on the screen on a position exactly 25 cm up, down, left or right with respect to the previous position. The set of items found at that new location is shown, and the green square moves accordingly to indicate the new active location. As before, any of the item images can be clicked to obtain the information about the item. The available information by interacting the images are category, price, comments and ratings.

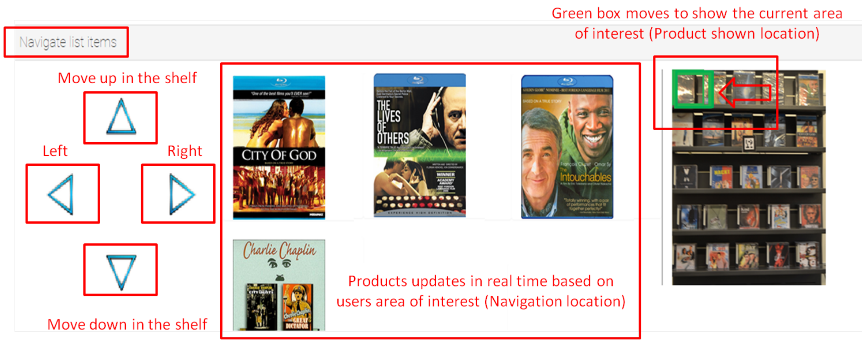

Figure 7.4: Navigate in the shelf.

7.3.4 Search for an item

At any time the user can use a search box to search for a given text string. All the items containing this string within any of the information fields in the database (e.g. title, author, description, etc.) will be listed (or an error message will be shown if no items match the search string). When the user selects one of them, the green square will move to the location where the selected item is found on the shelf, and the images of all the items found within 25 cm of that location will be shown at the bottom of the screen. From here the user can choose to see the information about any of the located items, can click on a different shelf position, or can browse around the shelf using any of the four arrows.

7.3.5 Retrieval of an item

All the aforementioned interfaces incorporate an *add to list* icon on the screen. With this icon, users can make the list of items to be purchased, and collect them at the checkout counter. The selected item list is constantly being updated at the counter section of the store in real-time. The user can call the shop assistance to retrieve browsed or selected items from the shelf, with the help of an assistance icon.

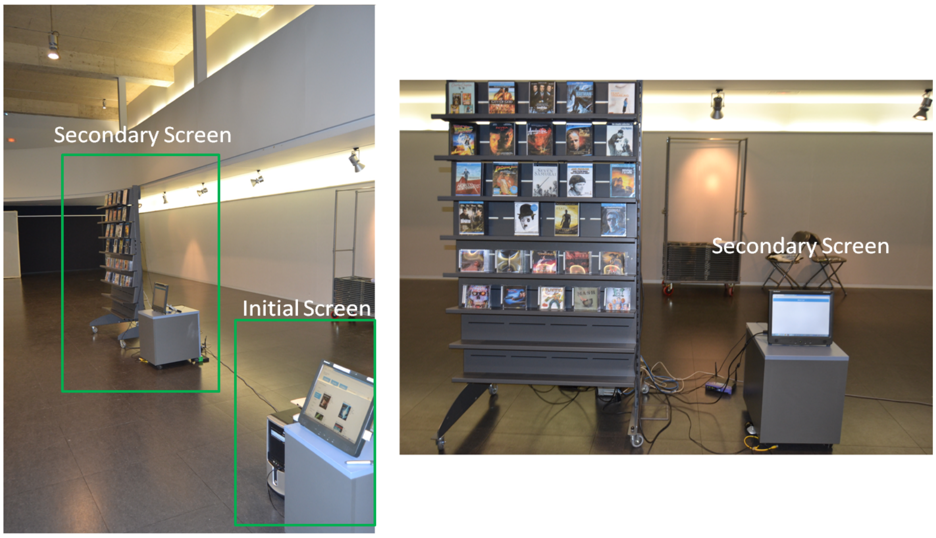

Figure 7.5: Initial Touch Screen is Placed at the Entrance of Shop and Second one close to the Shelf.

Chapter 8

H3 CATEGORY INTERACTION IMPLEMENTATION

In this chapter group *H3* is selected and focused for the further study i.e. poor or no hand mobility. It is worth noting that *H1* and *H2* users, as well as non disabled users, can also use any solution designed for the *H3* category. System overview is shown in Figure 8.1 and 8.7. System is evolved from the primary system named as *Smart Glass tethered with Head-beam light*. Below both the systems are explained in detail. We divide the system into two main parts i.e. physical space that can also be called offline space, and AR interfaces that can be referred to as online world. In the physical world we have items equipped with RFID. The RFID system contains antennas connected through a multiplexer to the reader. The reader is then connected to the host controlling the RFID system. It inventories all the items present on the shelf and makes this shelf a Smart Space. In the Smart Space we have the information about the items present with their precise location. All the information about the items is then passed to the server through the RFID host. The second part referred as online part captures the user interaction. User interactions are being converted to the physical coordinates with the help of Smart Glass AR application. After processing, these coordinates are passed to the server. AR application translates digital world coordinates obtained through user interaction to physical world coordinates. Both online world and offline world are interconnected through server and constantly being synchronized.

8.1 Smart Glass Augmented Reality System

After a certain period of time focusing on a specific shelf area, information is displayed on the Smart Glass as an AR interface. We have used AR markers to map the physical space coordinates, distance and orientation between users and shelf. Once items information is presented at Smart Glass, users are bridged from offline world to online. From the Smart Glass interface user can access online information about the items including price, size, user comments, etc. Item detection, localization, contextualization and presentation on the real environment through AR and RFID are performed on the Smart Glasses and Smart Spaces. In this case we have implemented *Cricking* by means of Smart Glass AR interfaces collaborated with RFID. When the user focus on the shelf and remain withing 25 cm for 3 seconds, it will be considered as a click on that particular focused area.

8.1.1 Smart Glass tethered with Head-beam light

We have developed a system comprised of Smart Glass, Smart Space, head beam light and Smart Phone that enables the user to browse the physical space. Figure 8.1 shows the system overview. Our target space in current scenario is a shelf. The shelf is equipped with the RFID system and adjusted with head beam light. RFID turns the shelf into Smart Space by which all the items present on the shelf can be inventoried and localized. Head beam is used to have a cursor effect, user can move the head beam light focus on the shelf at particular location with the help of a Smart Phone and can click at particular location on the shelf. The information about the items present on the user’s clicked location on the shelf will be displayed on the HUD or Smart Glass as smart interfaces. Once the items are presented at Smart Glass users are bridged from offline world to online. From the Smart Glass interface user can access online information about the items including price, size, user comments, etc.

Methods and Procedure

In the proposed project different components of systems are communicating with each other via WiFi LAN. The main components of system are explained below.

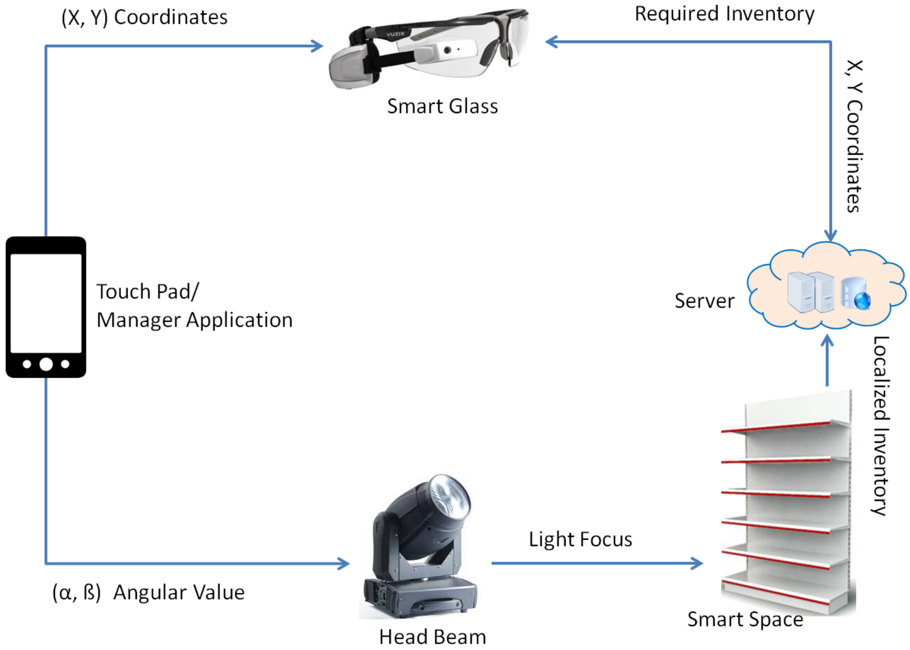

Figure 8.1: System Overview. User interacts with the manager application that sends cartesian coordinates and angular coordinates to Smart Glass and head beam, respectively. Head beam lit up the Smart Space using angular coordinates and Smart Glass retrieve the user's requested data from server using cartisian coordinates.

Figure 8.2: Smart Space with Head Beam Light.

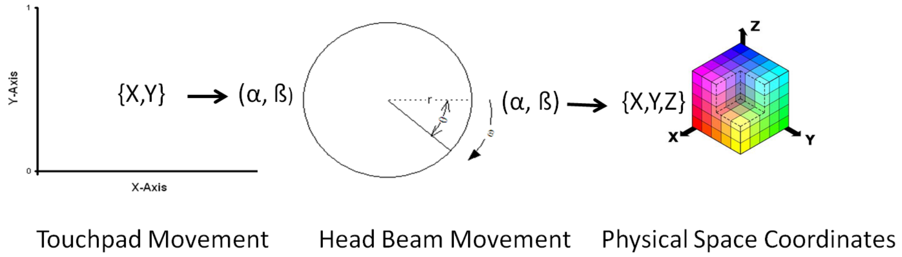

Figure 8.3: Coordinates Synchronization.

Manager Device

The mouse is replaced by a Smart Phone acting as a touch pad, and performs *Cricking*. We termed this Smart Phone as Manager Device, as the main processing algorithms are implemented and executed in this device. Smart Phone touch screen can be used for *Cricking*. *Cricking* can be described as the position where the user stops moving the light. That particular area of shelf will be considered as the click area or user's point of interest.

Head Beam Light

The head beam light is mounted in front of the shelf and act as cursor and to highlight the user's area of interest. It moves to change the light focus on the shelf with the relative movement of user scrolling on the Smart Phone. Figure 8.2 shows the shelf mounted with head beam light.

Smart Glass

Vuzix M100 Smart Glass in used in the current case. Figure 8.4 shows the Smart Glass. It receives shelf coordinates form the Manager Device and connects to the database for retrieving inventory from a particular location. Once the particular inventory is received, Smart Glass constructs the interface. Figure 8.6 shows one screenshot of the Smart Glass interface.

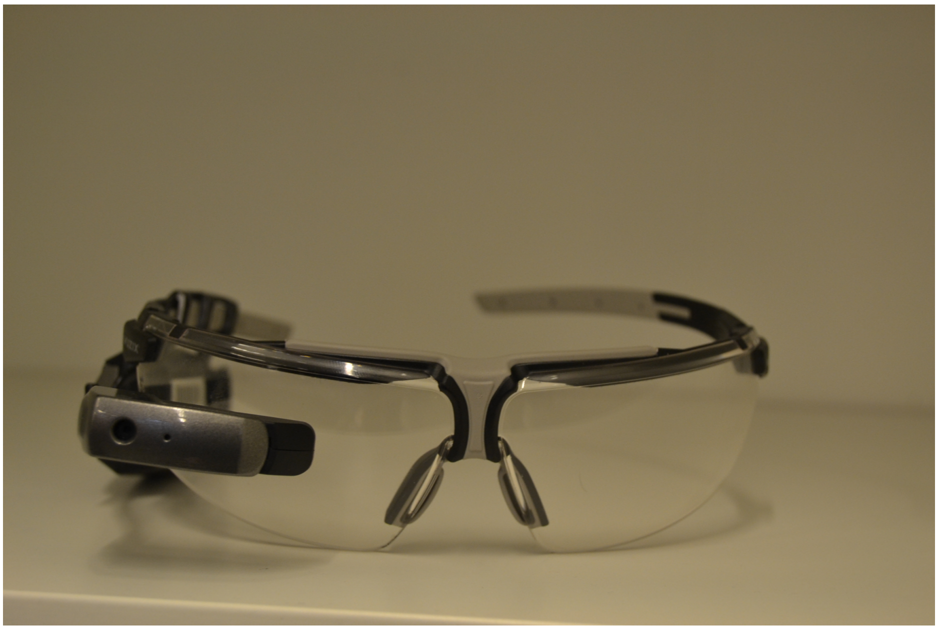

Figure 8.4: Vuzix M100 Smart Glass.

Internal System Design

The proposed system is comprised of sub modules that run on different devices. The main module executes in Smart Phone which is developed in android that controls the whole system. It captures the finger movement, coverts it to the spherical coordinates through the implemented algorithm and sends them to the head beam light via UDP datagram channel. It also converts spherical coordinates to 3D shelf coordinates through designed and implemented algorithms based on trigonometric functions and sends them to Smart Glass. For the head beam light there is an application developed in java that runs on a PC. It receives the spherical coordinates and moves the light to a particular position. Smart Glass executes an android application that receives 3D coordinates and connects to the server for inventory. The RFID system automatically inventories and localizes the items present on the shelf and updates the server. All the communication between different components of systems is done through WiFi LAN. Figure 8.3 shows conceptualization of different devices coordinates synchronization.

Figure 8.5: Final Working System.

General System Usage

User is provided with the Smart Glass and Smart Phone. Now, the user can use the Smart Phone as a touchpad to move the head beam light and lit the particular area on the shelf. All the items present under the lit area of the shelf will automatically be presented to the Smart Glass interface. From where the user can interact with them. If some items are removed, added or location has been changed, this can be detected by the system and user will always get the real-time results with updated location. Figure 8.5 shows the users interacting with the system.

Figure 8.6: Smart Glass Interface.

8.1.2 Standalone Smart Glass Application

Augmented Reality and RFID technologies are used to link offline objects to online features. Both technologies complement each other, RFID is becoming essential for retail because of numerous properties it offers, and AR allows enriching the user view by providing information about the environment. RFID inventories and localizes the products, and AR captures user position, orientation, and interaction, showing information on top of a real shelf. Next, we detail the building blocks of our proposed system. System overview is shown in Figure 8.7. We divide the system into two main parts i.e. physical space that can also be called offline space, and AR interfaces that can be referred to as online world. In the physical world we have items equipped with RFID. The RFID system contains antennas connected through a multiplexer to the reader. The reader is then connected to the host controlling the RFID system. It inventories all the items present on the shelf and makes this shelf a Smart Space. In the Smart Space we have the information about the items present with their precise location. All the information about the items is then passed to the server through the RFID host. The second part referred to as online part that captures the user interaction. User interactions are being converted to the physical coordinates with the help of AR application. After processing, these coordinates are passed to the server. AR application translates digital world coordinates obtained through user interaction to physical world coordinates. Both online world and offline world are interconnected through server and constantly being synchronized.

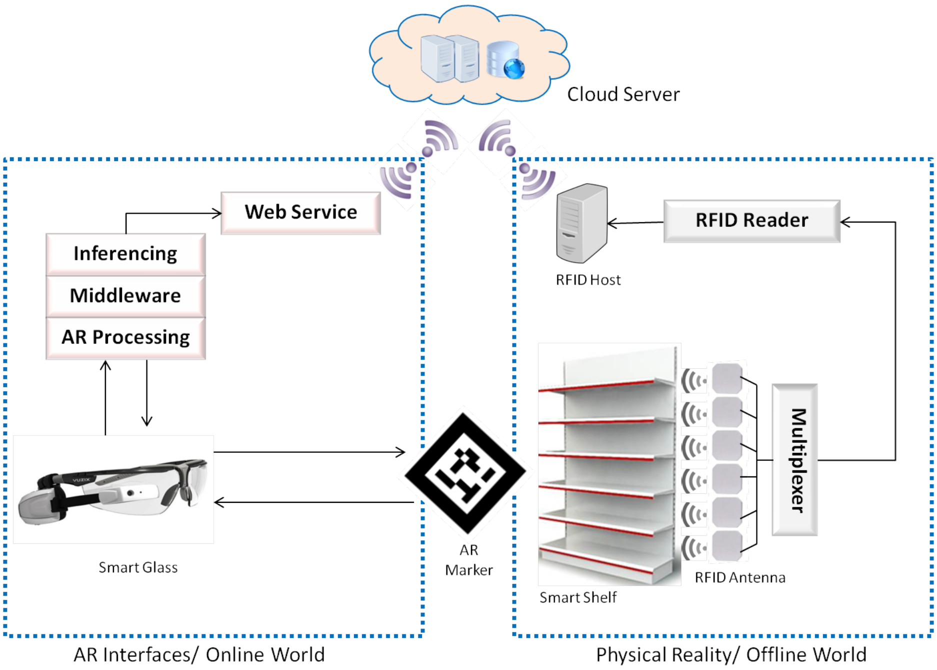

Figure 8.7: System Overview. In offline world RFID system inventories and localizes all the items present on the shelf and sends those to the server through RFID host, While in online world Smart Glass application dynamically contextualize all the items by accessing the server and construct AR interfaces at user click location with the help of AR marker. Both offline world and online world are interconnected and synchronize in a real-time.

Methodology

Vuzix M100 Smart Glass [Vuz, 2014] is used in the current case. When the Smart Glass is focused or aimed to the shelf at particular location for certain period of time (3 seconds in the current case), it uses an AR marker placed on a known position of the shelf to determine the origin, scale and rotation of the shelf coordinates with respect to the Glass screen coordinates. The position and orientation of the user is also calculated with the help of AR marker. AR marker can be of variant size, depending upon the desired distance between shelf and the user. If user wants to keep more distance bigger size marker can be used. We are using 12cm maker that allows user to stand up to 3.5 meters far from shelf covering the 100 * 120 cm area of shelf. When a user clicks, the coordinates of the corresponding shelf position are calculated by the AR system. Click is considered when user focuses or aims the same area for a certain period of time. A web service obtains a list of all the Electronic Product Code (EPC) codes that the RFID system has reported as located within a certain distance of such shelf position. A further web service call obtains the information and images of those objects, which are shown by the AR application on the screen. An area of interest referred as red square superimposed on the shelf live image indicates at all times the area about which the information is being shown. Interactive images of the items are shown at the bottom of the screen, where the user can select the image of the product with a Smart Glass gesture, or voice interface to further explore the related information. The user can go to online stores with the particular product selection (i.e. Amazon, eBay, etc.) and can analyze product ratings and compare prices. Figure 8.8 shows the final working system and Figure 8.9 shows a screenshots of the Smart Glass interface.

Internal System Implementation

The RFID system produces a list of the EPC of every object on the shelf, and its approximate location, and stores it in a local computer. A database stores information about every possible product class (a.k.a. Stock-Keeping Unit - SKU), including their images. Every time a new object is added to the system, the EPC code of its RFID tag is added to the database, linking it to the particular product class. This way product information is normalized, stored only once per product class, even though many objects (product instances) of such product class are present. An inventory list, consisting of all the EPCs of the objects present on the shelf, together with their approximate locations is periodically uploaded to the database from the local computer of the RFID system. The cloud database is built using a Postgres DBMS. We have divided the shelf into segments based on the RFID accuracy, each shelf segment is 25 * 25 cm. All the items present within one segment will be regarded as one location. The identification of different segments of shelf is done through transformation matrix and Metaio SDK [AR-, 2010] build on Android operating system. Vuzix Smart Glass supports both Metaio SDK and Android SDK. A red square is drawn in the center of the

Smart Glass screen in order to give user the focus area, once the user keep the specific area of shelf under red square it is considered as user area of interest and click location, Always the center of the screen pixels i.e. mid of screen are passed to the AR SDK in order to calculate the X, Y and Z coordinates on the real plane i.e. shelf. Once user's areas of interest coordinates are calculated, a number of products that are present at that X, Y and Z coordinates are inquired by the RFID system. The RFID system inventories and localizes the products in terms of their X, Y and Z coordinates in a cyclic manner. In this way both AR system and RFID are collaborating with each other by synchronizing and sharing the coordinates of the products through a server in a real-time. A web service returns the list of all objects which are reported by the RFID system to be within 25 cm of the calculated coordinates. Another web service call obtains all the information available about the objects, including the images. Since the products used are DVDs and CDs, the images of the set of products are presented with interactable Cover Flow interface at the bottom of the Smart Glass screen. User can interact and scroll the products images in the horizontal and vertical direction with the help of gesture control provided by Vuzix Glasses. The information can be seen by interacting the images are category, price, comments and ratings etc.

When the focus time is greater than 3 seconds on the same region of the shelf then algorithm detects it as click or if user focus moves from one segment to another (move grater than 25 cm), For computations of different segments we have used formula as shown in below mentioned equations. The identification of different segments of shelf is done through transformation matrix and metaio SDK. m and n represent the different segments of the shelf and x and y represent the axis location while c is a constant representing RFID accuracy.

$$m = floor\left[\frac{x}{c}\right] + 1 \tag{8.1}$$

$$n = floor\left[\frac{-y}{c}\right] + 1 \tag{8.2}$$

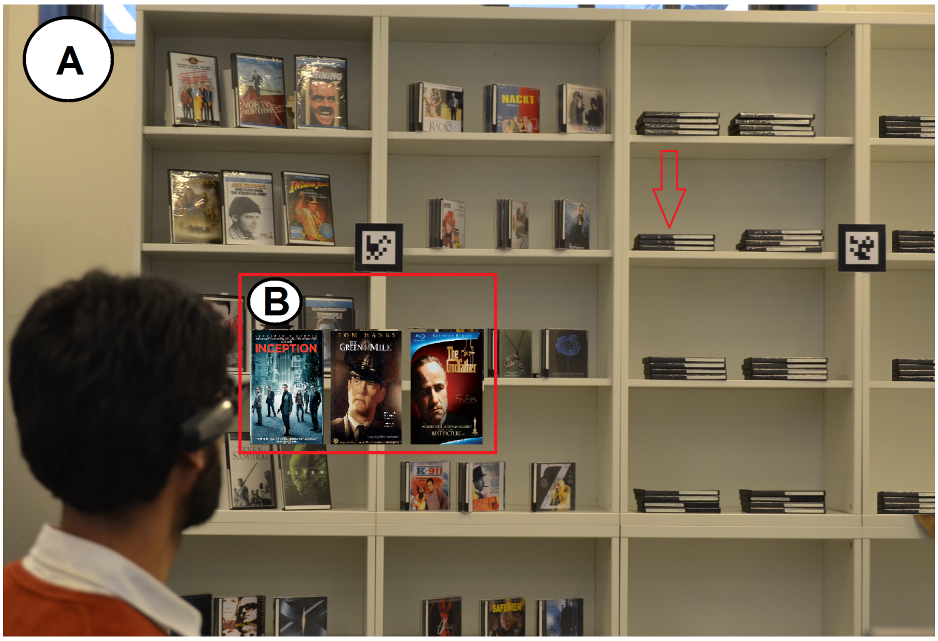

Figure 8.8: A: User is aiming at particular point highlighted with red arrow on the shelves with Smart Glass AR app for a 3 Seconds. B: The items present at user clicked location are shown on the Smart Glass as superimposed images with product information.

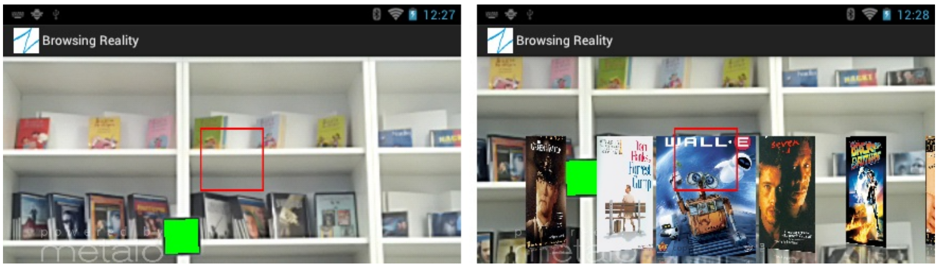

Figure 8.9: A: User is focusing at particular location. B: Results shown at user focused location.

Chapter 9

EVALUATION

In previous chapters, we have described the systems to allow wheelchair users to perform shopping activities in an autonomous and independent way, by considering the needs and suggestions collected in an initial user study. In this chapter we evaluate the proposed system within a controlled environment emulating a store, we will explain the evaluation of the proposed systems performed with the different category of wheelchair users. We choose the representative users for each of the system evaluation [Sears and Hanson, 2012]. All the wheelchair participants who participated in the end user system evaluation took part in the initial user study. We also introduced a control group for every system validation in order to calibrate the systems. Each participant followed a standard evaluation protocol [Dix et al., 2003] including:

1. The participant read and signed a consent form.
2. The participant was told the goal of the experiment.
3. The rest of the experiment procedure was outlined and explained for the participant.
4. Each user interface (initial and secondary screen interface) was demonstrated for the participant.
5. The participant was given the chance to practice.
6. The participant used the interfaces for a maximum of 30 minutes.

7. The participant answered the interface experience questionnaire for the overall system.

9.1 Evaluation for *H1* Category

Same participants of *H1* category from initial study participated to use the system for evaluation. Five wheelchair users with an average age of 40, including four male and one female. The detail of the preliminary evaluation are explained below:

9.1.1 Evaluation Design Environment

As a pilot application for testing the system, we have implemented a Virtual Shop in a university department. The Virtual Shop simulates the real shop or super market environment with shelves full of products. Figure 9.1 shows the experimental setup at university department termed as Virtual Shop. The overall height of the shelves is 200 cm and width is 240 cm. We regard these groups of shelves as one shelf. In order to cover the whole surface a RFID antenna is placed at every 25 cm distance both in horizontal and vertical direction, so 16 rows of 8 antennas were used. Since the reader only has four antenna ports, eight 1-to-8 multiplexers are used. Four AR markers of 12cm are used to map the whole physical surface of the shelf to the Smart Glass screen coordinates. These markers are detectable up to 3.5 meters distance from the shelf. 150 RFID tagged products including CD's and DVD's are placed at different locations on the shelf with different placement, some are stacked and the cover is visible to the user, and some covers are not visible to the user. Nevertheless, the RFID reader detects all the items even without being in line of sight. The user points with the tabled on the shelf for at least 3 seconds (click time- adjustable). When the user aims at particular point on the shelf for three continuous seconds, the information about the products present at that specific location is shown as AR interfaces on the Tablet. The user is then able to interact with these items through AR interfaces. The system has shown an accuracy of more than 99% in detecting and showing all the products on the Smart Glass screen correctly at the right location. If the product is removed or location is updated it will be reflected to the interfaces in real-time.

Figure 9.1: Experimental Setup.

9.1.2 Usability Study

Through all the experiment, users were observed by researchers to notice any problem or impediment with the system utilization. The analysis consisted on retrieving both qualitative and quantitative results. Qualitative results rely on observations and participants opinions. For quantitative results, every user were requested to perform tasks that include product selection, search for particular product, localization, and purchase a particular product during the usage of the system. All the tasks were conducted in random order (the counterbalancing principle of usability evaluation [Preece et al., 2015]). Each user was given 30 minutes to interact with the products and shelf through interfaces. After using the interfaces and completing all the tasks, each participants answered a final questionnaire, with open and closed questions. The objective was to analyze the satisfaction with each interaction method and interface in terms of easiness, and also to evaluate the efficiency of the interface and the considered features. We make use of *Likert* scale with points from 1 (strongly disagree) to 5 (strongly agree). The questions asked include:

1. How do you think this will help to give you independence in terms of shopping or browsing?

2. Were these interfaces useful to you?
3. How easy was it to visualize and interact with the product information?
4. Are you satisfied with the current level of options?
5. How much did you enjoy using the application?
6. How easy was to use the application?
7. Any other comment or suggestion?

The control group (C1, C2, C3, C4, C5) without any kind of motor disability, was asked to perform the same set of tasks that were requested to the wheelchair users, prior to the user study session with the motor disabled people. This control group was used for calibrating the user study.

Figure 9.2: Wheelchair Participants of *H1* category are interacting with the Shelf through AR App.

Table 9.1: Control Group Product Interaction Performance

User	Browsed	Searched	Localized	Purchased
1	7	3	5	2
2	5	4	3	1
3	6	4	4	1
4	7	4	2	3
5	9	3	4	4

9.1.3 Results and Discussion

Figure 9.2 show a final working system where wheelchair participants of *H1* category are interacting with the Shelf through AR app. After using the system users were very excited to know and use the system. The control group was able to *Browse Search, Localize and Purchase* 6, 5, 5 and 4 products receptively through Hand-held device interfaces. In comparison to the control participant, *H1* category participants *Browse Search, Localize and Purchase* 4, 3, 3, 2 products on average. Individual performance of each participant of control group and wheelchair participants from *H1* category is shown in Table 9.1 and 9.2 respectively.

When asked about having such a system for them at shops or being owned by them in context to their independence, participants strongly agreed by selecting 5 points on average. In response to the question of available option (Question 4), participants seemed less satisfied and chose 4 points on average. Participant S7 gave 3 points out of 5 that were the lowest score among all questions and participants. In the comment section S7 wanted to have it connected to social networks and other online features available. Overall questionnaire responses are shown in Figure 9.3.

During the evaluation, participants were observed keenly. We analyzed that the users felt more comfortable with the Smart Phone instead of Tablet. Handling the Tablet, while remaining on the wheelchair was a cumbersome task. On the contrary Smart Phone was easily manageable by them. The interaction method, we proposed i.e. to tap on the screen of Hand-held device while focusing the shelf was feasible and easy to perform. The technologies we used in the system are state of the art technologies and readily available. RFID has already became very common in the the shops and Smart Phone usage in on the rise. Our system

Table 9.2: *H1* Category Wheelchair Users Product Interaction Performance

User	Browsed	Searched	Localized	Purchased
1	5	3	5	2
2	4	2	1	1
3	5	3	3	2
4	3	4	4	2
5	4	2	2	1

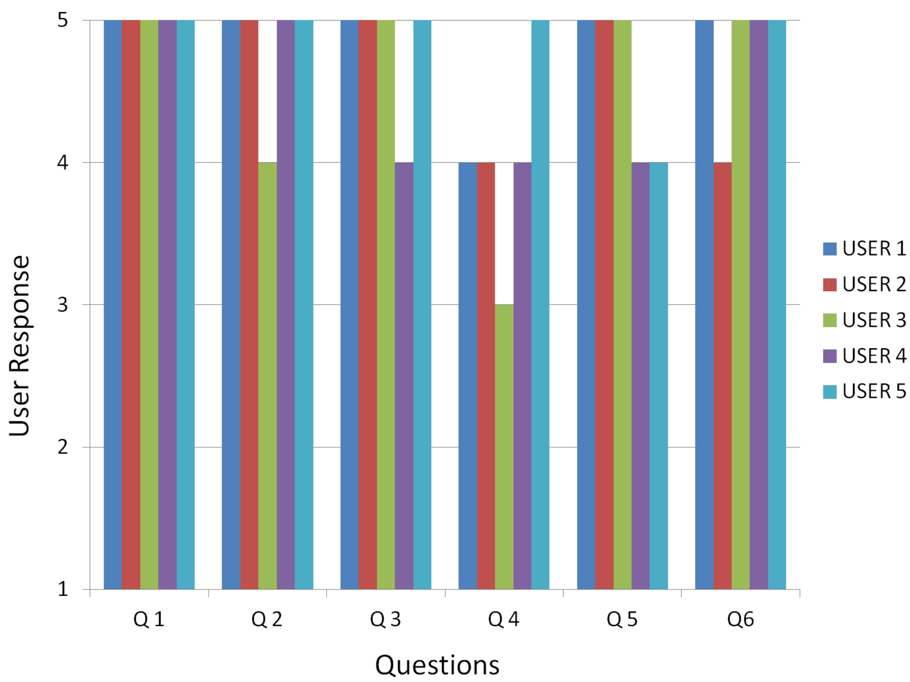

Figure 9.3: Questionnaire Responses of *H1* Category (cf: Section 9.1.2)

can also be used by the general public for bringing online shopping features to the offline retail. The usage of the system by general public helps the wheelchair user to cope with the stigma of being special or separated.

9.2 Evaluation for *H2* Category

A preliminary evaluation test has been performed with 8 users, including 4 physically disabled people and a control group of 4 able-bodied people, in a controlled environment emulating a store [Sears and Hanson, 2012]. Four wheelchair users who participated in the initial study with shaking hand movement (*H2* Category) participated in evaluating the system. Three of them were female and one was male with an average age of 42.

9.2.1 Evaluation Design Environment

As a pilot application for testing the system, we have implemented a Virtual Shop in a laboratory. Figure 7.5 shows the Virtual Shop setup with two touch screens and a Smart Shelf with products. The Virtual Shop simulates the real shop or super market environment with shelves full of products. An initial touch screen was placed at the entrance of shop along with the second screen at a distance of 10 meters close to the Smart Shelf. We used 14 inches touch screens. Smart Shelf has a height of 200 cm and width of 100 cm. A total of 150 products were placed on the shelf. These products were DVD´s and CD´s. Products were stacked in groups of 5, so that only the first DVD or CD cover was visible. The remaining four products were hidden from user perspective, however, since RFID does not require direct line of sight, it can detect and locate all the hidden products.

9.2.2 Usability Study

After the step no 3, in which users read and listened to the volunteer about usage of system. The volunteer demonstrated the system by using it. Firstly volunteer used the initial screen accompanying with the wheelchair users and performed all the uses cases available at the initial screen then she moved to the secondary screen along with the participants and used all the use cases available at secondary screen. After that in step 4, each of the participants were asked to repeat the process by using both the initial and secondary screens and perform shopping life cycle. After every participant practiced the system and get acquainted with the technology and use cases, they were asked to use the system and purchase some products. During this step each of participant were observed keenly and noted in order to analyze the usage of system by them. Every user were given 30 minutes individually to interact with the system. During the practice session,

Figure 9.4: A) Back of a Smart Shelf showing the RFID System. B) Frontal view of Shelf with RIFD tagged products.

it was found out that users were not familiar with the technology and having difficulty to touch the screen properly, also they were confusing between initial screen and secondary screen purpose. During the practice session, they were continuously asking questions. They got acquainted with system use cases and technology and started to perform tasks independently and more comfortably. In practice session they were mainly explained about the use cases and life cycle of system, we trained them how to touch the screens and wait for sometime in order to give system some processing time, how the screens are connected to RFID Smart Shelf to provide real-time inventory. One complete life cycle of shopping and all the use cases of system were performed individually and together with users during step 4 and 5.

Through all the experiment, users were observed by researchers, to notice any problem or impediment with the system utilization. Every user was given 30 minutes to interact with the shelf, select products, and see the product information. Researchers took special attention to two main objectives: *understanding of the system* and *proper utilization of the system*. The specific tasks the users were requested to perform include: *Product Selection*, *Product Search*, *Product Localization* and *Easiness during the usage of System* (cf. Section 7.3). Finally, a open ended questionnaire was prepared in order to conduct the usability study. Two open ended questions were asked to summarize their experience and satisfaction with the system:

1. Do you think the technology used in the experiments was easy to use?

2. Do you think the interfaces in the experiment can help you in browsing, shopping and gives you more autonomy and independence? Please, detail your experience?

The control group (C1, C2, C3, C4), without any kind of motor disability, was asked to perform the same set of tasks that were requested to the wheelchair users, prior to the user study session with the motor disabled people. This control group was used for calibrating the user study.

9.2.3 Results and Discussion

For control group of 4 able-bodied people results are shown in Table 9.2.3 with their individual performance. Here we will conclude their performance in average. They used the system for 23.5 minutes in average. They interacted with 15 products from the initial screen (cf. Figure 7.2) and with 11 products form the secondary screen (cf. Figure 7.3) in average. All participants were given practice session after demonstration of system. During that time, they were able to use the system independently, though they faced difficulties in touching the proper icon or text. Sometimes during the system processing time, they pressed again some other icon as they were not familiar with the technology in detail. However they performed the complete life cycle of shopping by searching, browsing, locating and choosing the product from both the screens. For the browsing in the shelf we used 4 arrows to browse in vertical and horizontal direction but for them it was the most difficult task to perform by clicking exactly on the screen. They preferred to click on shelf image instead and get the corresponding product information for the real shelf. Before they started individual use of system they were told they cannot ask for help and they have to perform the the task by themselves. At Initial Screen that was present at the entrance of the store, they were

Figure 9.5: A) System is being demonstrated to the users. B) Wheelchair users are practicing the system. C) Wheelchair user is interacting with the initial interface that is placed at the entrance of the shop. D) User is interacting with the secondary interface that is placed near to the shelf.

Table 9.3: Control Group Product Interaction Performance

User	Initial Screen			Secondary Screen		
	Searched	Selected	Localized	Searched	Selected	Purchased
1	4	6	5	1	5	4
2	5	5	3	3	6	3
3	5	5	2	2	4	2
4	7	8	3	4	5	5

able to search 4 products in average (cf. Section 7.3.1, 7.3.4). They selected 4 products for further details form the initial screen that is termed as Selected (cf. Section 7.3.2). From the initial screen users localized 2 products and passed it to the second screen for further processing on average (cf. Section 7.3.2). At the secondary screen that was close the shelf they further searched 2 products and selected 3 products for the details (cf. Section 7.3.3, 7.3.4, 7.3.2). On average they purchased 3 products (cf. Section 7.3.5). Individual life cycle and participation is shown in Table 9.2.3. On average the wheelchair users interacted with 10 products from initial screen (cf. Figure 7.2) and with 7 products from the secondary screen (cf. Figure 7.3).

From observation, we conclude that the users were successfully able to use the implemented use cases of the system. They felt comfortable with touch screen interfaces and all the interfaces were readable and touchable by them (though it took sometime i.e. practical session). Each of the user successfully completed the life cycle of shopping that includes the search and add to list from the initial screen (store entrance) to arrive the secondary screen (close to shelf) for product detail information, specific location and selection. Initially they felt difficult to interact the touch screen because of unfamiliarity, but with practice they got acquainted and started enjoying the system. Figure 9.6 shows the user interaction with the system, users have given the consent to use their images for research purposes. Next, we summarize the responses of the participants to the questions asked, as the users felt uncomfortable and difficult to write, a volunteer was accompanying them to facilitate in writing.

All the participants described the technology used as easy and usable. It is worthwhile to mention their comments as they incline with the previous studies in terms of technology usage [Stenberg et al., 0] [Chib and Jiang, 2014]. Particularly the use of touch screen is regarded as the most appropriate approach for the

Table 9.4: *H2* Category Wheelchair Users Product Interaction Performance

User	Initial Screen			Secondary Screen		
	Searched	Selected	Localized	Searched	Selected	Purchased
1	2	3	2	1	3	3
2	4	4	1	2	4	2
3	3	3	2	2	4	2
4	6	4	2	1	2	3

people with motor disabilities with higher degree of impairment [Pires et al., 2010a]. The response to Q2 is explained below, as the local language is Spanish, these answers are translated to English.

S1
After using the system I can say that it will be beneficial for everyone on wheelchairs because its necessary for us, and apart from this, all trade (e.g. supermarkets, shops) should incorporate it.

S2:
I think system is interesting, and for buying products independently, It is interesting to know and get the information of the products that was not possible before.

S3:
Current experiments have been done with CD´s and DVD´s that are interesting, If the same system has been implemented for shops and supermarkets that includes clothing and items we consume every day, it would be a great for people in wheelchairs. For day to day activities, and all purchases people do on wheelchairs, this technology help us to attain our independence and maintain our privacy by any store, without needing help and would result in gaining personal autonomy.

S4
These interfaces are helpful to me to do shopping by myself without asking or requiring the assistance of other people. I would like to have it available at real shops, and that getting used to something like this is very easy, and it is an opportunity to be more independent.

Findings of our study further consolidate the previous study findings regarding wheelchair users [Caon et al., 2012] [Pires et al., 2010a], the methods of interaction proposed by previous studies have been adopted effectively in combination with RFID. The overall results of preliminary study provides wheelchair users a complete independent and autonomous shopping experience.

First step towards the evaluation of the system has been to let the target users practice and use the designed use cases. Due to the reduced number of representative participants, we introduced a control group as well as detailed users description [Sears and Hanson, 2012]. However, it was noticed in particular that for *H2* category wheelchair users, it was difficult for them to interact through technology. Initially, they were not able to tap on the right spot on the screen and facing difficulties to read from the screen. Performing tasks thorough computer screens was new to them. As they need to have bigger fonts and images to visualize and touch screen, they never used typical computers before in general. The main disadvantage found in the evaluation is the precision required to tap the icons or texts. For this we propose to use more bigger screens with more bigger fonts. During the observation it was revealed that users needs sometime to feel comfortable with the system, since they need some practice to touch at the specific area of the shelf(shaking hand movement). Overall, users find the system easy to use, intuitive and practical. During the experiments users were excited to know and use such a system, they felt motivated to have such a system at real shops. All the participants understood the system and used it properly and was eager to find it in real stores. We used 14 inches touch screen with big fonts and images, however, users would have preferred a bigger screen. All the participants were agreed on a point was that they like to see a system at a real shop implemented, working and available to them, so they can take benefit out of it in their everyday life. Our proposed interfaces and interaction method provide a people with motor disabilities to become a more active part of society and thus improve their social inclusion. We utilized and enhanced the previous studies for people with (motor) disabilities [Miguel Sales Dias, 2012] [Pires et al., 2012] and took them to practical and real life scenario of Shopping.

9.3 Evaluation for *H3* Category

Three *H3* category wheelchair participants participated in the final evaluation of the system. Two of them were male and one were female with an average age of 53. Details of the preliminary evaluation of *H3* category system are explained below:

9.3.1 Evaluation Design Environment

Evaluation design environment for *H3* category is same as *H1* category with little variations. Figure 9.1 shows experimental setup at Virtual Shop. The overall height of the shelves is 200 cm and width is 240 cm. We regard these groups of shelves as one shelf. In order to cover the whole surface a RFID antenna is placed at every 25 cm distance both in horizontal and vertical direction, so 16 rows of 8 antennas were used. Since the reader only has 4 antenna ports, 8 1-to-8 multiplexers AdvanMux-8 are used. 4 AR Markers of 12cm are used to map the whole physical surface of shelf to the Smart Glass screen coordinates. These markers are detectable up to 3.5 meters distance from the shelf. 150 RFID tagged products i.e. CD's and DVD's are placed at the different locations of the shelf with different placement, some are stacked and cover is visible to the user and some with cover not visible to the user as RFID detects all the item without being in line of sight. User is given Glasses to aim or focus at any point or location on the shelf for at least 3 seconds (click time adjustable). When the user aims at particular point on the shelf for three continuous seconds, the information about the products present at that specific location is shown as AR interfaces on the Smart Glass. User is able to interact with these items through AR interfaces. System has shown an accuracy of more than 99 % in detecting and showing all the products on the Smart Glass screen correctly at the right location. If the product is removed or location is updated it will be reflected to the interfaces in real-time.

9.3.2 Usability Study

Through all the experiment, users were observed by researchers to notice any problem or impediment with the system utilization. The analysis consisted on retrieving both qualitative and quantitative results. Qualitative results rely on observations and participants opinions. For quantitative results, every user were requested to perform tasks that include product selection, search for particular product, localization, and purchase a particular product during the usage of the system. All the tasks were conducted in random order (the counterbalancing principle of usability evaluation [Preece et al., 2015]). Each user was given 30

Figure 9.6: *H3* Category Wheelchair User is Interacting with the Shelf through Smart Glass App.

minutes to interact with the products and shelf through interfaces. After using the interfaces and completing all the tasks, each participants answered a final questionnaire, with open and closed questions. The objective was to analyze the satisfaction with each interaction method and interface in terms of easiness, and also to evaluate the efficiency of the interface and the considered features. We make use of *Likert* scale with points from 1 (strongly disagree) to 5 (strongly agree). The questions asked include:

1. How do you think this will help to give you independence in terms of shopping or browsing?
2. Were these interfaces useful to you?

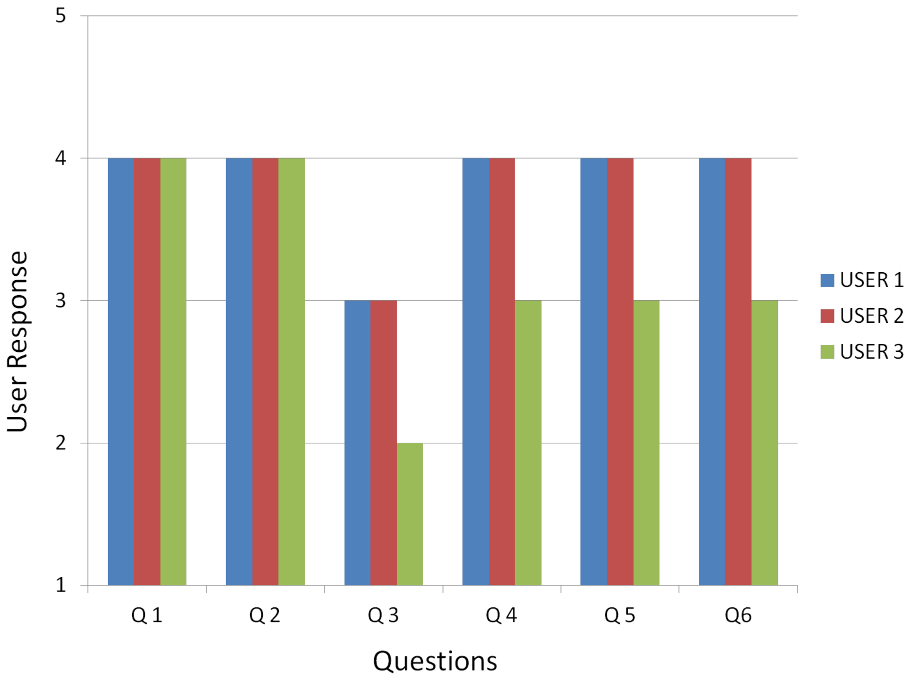

Figure 9.7: Questionnaire Responses of *H3* Category (cf: Section 9.3.2)

3. How easy was it to visualize and interact with the product information?

4. Are you satisfied with the current level of options?

5. How much did you enjoy using the application?

6. How easy was to use the application?

7. Any other comment or suggestion?

The control group (C1, C2, C3) with an average age of 41, without any kind of motor disability, participated in the evaluation in order to calibrate and compare the system results.

Table 9.5: *H3* Category Wheelchair Users Product Interaction Performance

User	Browsed	Searched	Localized	Purchased
C1	9	3	4	2
C2	10	2	3	2
C3	10	3	5	2
S14	6	1	1	1
S15	9	1	0	2
S17	10	1	0	1

9.3.3 Results and Discussion

For *H3* category, we got mixed results. The control group was able to *Browse Search, Localize and Purchase* 9, 3, 4 and 2 products receptively through Smart Glass interfaces. While on the other hand *H3* category participants were successful to browse 8 items on average. They were successful in finding one product each. Localization remained a cumbersome task to them with the result of less than 1 on average. In the end wheelchair users of *H3* category were successful in purchasing 1 product on average. Poor mobility of arm and hand restricted them to lower results in searching and localizing the products. Individual performance details are shown in Table 9.5.

The participants of Smart Glass application evaluation gave a mixed response to the system. Question 1 got the highest points with 4 on average and Question 3 got lowest with 3 points, S17 gave 2 points in response to Question 3 of information visualization and interaction and mentioned poor eyesight, poor arm and hand mobility as a reason. Overall questionnaire responses from *H3* category are shown in Figure 9.7.

In case of Vuzix Smart Glass usage, we observed a number of issues. First, due to poor hand and arm mobility movements of *H3* category, participants were unable to interact with the check-in Touch Screen. Second, Smart Glass’ gesture and voice interface was difficult for them due to the technology shortcomings and their physical conditions. During the Smart Glass interface experiments, participants were comfortable in browsing the products from the shelf, as it involves only head movement. They were able to visualize the particular product information, but interaction with the product information was cumbersome task for them. Because of this *H3* category participants browsed more items but failed to search, localize and purchase items. Smart Glass voice recognition system and gesture detection would have been adapted to the *H3* category. More practice and time by the wheelchair users seemed useful to overcome these shortcomings.

Chapter 10

CONCLUSIONS AND FUTURE WORK

10.1 Conclusion

Motor disabled individuals are forced to stay at home more than they would like to. In order to overcome isolation, Information and Communication Technologies (ICT) are already being used by these individuals, to communicate not only with family but also with friends and acquaintances. Therefore, ICTs play an important role in motor disabled people’s lives, fighting isolation. Activities like shopping, going to library, take an important role in communication and social life inclusion, leading towards an independent living.

Independent living is a long term goal for motor disabled people. It means being able to do all or almost all daily activities without help or with minimal assistance from others. Wheelchair users, for instance, can not browse objects that are not within arms’ length in a store without requiring assistance. If they are high on a shelf, or inside a cabinet, or in a pile, it can be very difficult, if not impossible, to find and examine by a person that cannot stand up. Moreover, severe mobility impairment also affects the communication abilities of people, making them hard to understand to people not used to this specific issue. Hence, it is not only the fact that users may have troubles to access a specific store, but also they may find problems to communicate to the store personnel. Altogether, these users require a solution to improve their independence in this specific everyday activity.

Social awareness is increasing to bridge the gap between able-bodied and disabled. Wheelchair users are getting access to more spaces, venues and surroundings. We proposed a solution for the interaction with the spaces, venues and surroundings, focusing more on interaction with the items present beyond their arm length while remaining on the wheelchair. We presented a shopping scenario where wheelchair users are able to reach the store without assistance, but are unable to interact with the products without assistance. We provided the solution to access the products present on the shelf without assistance of a third person. Following the paradigm of Internet of Things (IoT), we focused at the interaction between people and simple object.

In Chapter 2, we have reviewed state of the art examples and systems available for the wheelchair users in order to gain autonomy in their personal life. We also mentioned restrictions and limitations posed by already existing systems and examples. Considering the previous studies we proposed a novel system for the motor disabled people. Our system provides solution for all the categories of the wheelchair users depending upon their degree of disability.

In Chapter 3, we presented the user study. The user study consisted of a preliminary controlled interview with a group of eighteen wheelchair users, with the objective of gaining insights into their current use of technology in general, and their shopping pattern, in particular. This user study enabled us to derive some guidelines and requirements of technology for the motor disabled people. The user study resulted in categorization of wheelchair users, according to their degree of disability.

In Chapter 4, we proposed a set of interfaces and technologies for independent shopping experience of motor disabled people. The interfaces and technologies are chosen in the light of user study and depending on the degree of disability of the wheelchair users. The chosen uses cases reflects the needs and requirements of the wheelchair users. We proposed the use of RFID based Smart Spaces and other readily available technologies.

In Chapter 5, we explained in detail the Smart Spaces based on RFID. We covered the different components of the RFID system. We explained in detail the different Smart Shelves and their specifications used in this study.

Chapter 6, 7 and 8 described the different system implementation details and number of use cases developed for the life cycle of wheelchair users shopping. We related categories of wheelchair users to each system and explained the development methods and procedures. Different interfaces developed were shown and detailed in these chapters. The systems were implemented mainly through Augmented Reality, Smart Phone, Heads-up Display and Touch Screen collaborated with RFID based Smart Shelves.

Finally Chapter 9, detailed preliminary evaluation performed for the proposed systems. Representative users from each category of motor disabled people participated in the evaluation and used the systems. Twelve wheelchair users participated in the evaluation. Initial evaluation returned positive results towards achieving the goal of independent living of motor disabled people.

The results of the overall study provides a valid approach to improve independence of wheelchair users while performing shopping activities, based on the needs and requirements specified in an initial user study. RFID enabled Smart Shelves inventory and localize all products in real-time. Then, an interactive interface at the entrance of the store allow the users to know about the availability of the product without the need to get in the store, which may represent a problem for wheelchair users. Finally, each Smart Shelf provides specific location and information of each requested product through interfaces based on different devices. The system was evaluated with wheelchair users with different degree of physical disabilities. It is worth mentioning that the proposed system would benefit not only wheelchair users, but also users with other impairments like reduced vision, as well as general population under the concept of *Cricking*. As the wheelchair users were categorized, evaluation was performed with the representative data for each category. The conclusions extracted from the evaluation show the satisfaction of users with the usability and simplicity of the system, being able to browse and interact with products autonomously and independently.

10.2 Future Work

The results of the preliminary evaluation with the representative data shows promising results towards the independent living of motor disabled people. In the light of users comments, system should be customized to the local languages in order to give it more visibility. More options like, connection to social media and other online portal would further benefit users experience. The proposed system can be extended to the libraries with the same specifications. The scope of the study includes the installation of the system to the libraries as they have the same infrastructure as shopping stores i.e shelves and narrow passages. A detailed evaluation with more wheelchair participants will further consolidate the proposed systems. During the current study we simulated the shop environment at university department but as a future work we plan to deploy the system at a real shop and perform detailed research of the system with random wheelchair users. Real shop scenario will give us further chances to improve the systems and meets the requirements of people with motor disabilities. Detailed questionnaire and interview should be performed to get qualitative and quantitative measurements in order to further enhance and enrich the system according to the requirements of wheelchair users.

Publications

10. *Using Augmented Reality and Internet of Things to Improve Accessibility of People with Motor Disabilities in the Context of Smart Cities*, **Zulqarnain Rashid**, Rafael Pous, Joan Melia, Enric Peig, Elsevier Future Generation Computer Systems, Special Issue on Smart City and Internet of Things (In Preparation).

9. *A smartphone application for voice browsing RFID smart shelves*, Kamruddin Nur, **Zulqarnain Rashid**, and Rafael Pous, Proceedings of the 2015 ACM conference on Mobile and Ubiquitous Multimedia (MUM).

8. *Towards Independent Living of Motor Disabled People through Mobile Augmented Reality and RFID*, **Zulqarnain Rashid**, Rafael Pous, Joan Melia, Enric Peig, Elsevier Journal of Pervasive and Mobile Computing (Under Review).

7. *Independent Shopping Experience for Mobility Impaired by Integrating Real-time Interactive Interfaces with RFID*, **Zulqarnain Rashid**, Rafael Pous, Joan Melia, Enric Peig, Elsevier International Journal of Human-Computer Studies (Under Review).

6. *Bringing Online Shopping Experience to Offline Retail through Augmented Reality and RFID*, **Zulqarnain Rashid**, Enric Peig, Rafael Pous, The 5th International Conference on the Internet of Things (IoT 2015), Seoul, South Korea.

5. *Bridging Offline and Online World through Augmentable Smart Glass Interfaces*, **Zulqarnain Rashid**, Joan Melia, Rafael Pous, LNCS- Springer International Conference on Augmented and Virtual Reality (AVR 2015), Salento, Italy.

4. *Cricking: Browsing Physical Space with Smart Glass*, **Zulqarnain Rashid**, Rafael Pous, Joan Melia, Enric Peig, ACM International Conference on Ubiquitous and Pervasive Computing (UbiComp 2014), Seattle, USA.

3. *Mobile Augmented Reality for Browsing Physical Spaces*, **Zulqarnain Rashid**, Rafael Pous, Joan Melia, Marc Morenza, ACM International Conference on Ubiquitous and Pervasive Computing (UbiComp 2014), Seattle, USA.

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