University of Nevada, Reno

# EXPLORING THE USE OF WEARABLES TO DEVELOP ASSISTIVE TECHNOLOGY FOR VISUALLY IMPAIRED PEOPLE

A Thesis Submitted in Partial Fulfillment
of the Requirements for the Degree of Master of Science in
Computer Science and Engineering

by
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# THE GRADUATE SCHOOL

We recommend that the thesis prepared
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**MANJU JOSE PALATHINGAL**

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# EXPLORING THE USE OF WEARABLES TO DEVELOP ASSISTIVE TECHNOLOGY FOR VISUALLY IMPAIRED PEOPLE

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requirements for the degree of

MASTER OF SCIENCE

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# ABSTRACT

This thesis explores the usage of two prominent wearable devices to develop assistive technology for users who are visually impaired. Specifically, the work in this thesis aims at improving the quality of life of users who are visually impaired by improving their mobility and ability to socially interact with others.

We explore the use of a smart watch for creating low-cost spatial haptic applications. This app explores the use of haptic feedback provided using a Smartwatch and Smartphone to provide navigation instructions that let visually impaired people safely traverse a large open space. This spatial feedback guides them to walk on a straight path from source to destination by avoiding veering. Exploring the paired interaction between a Smartphone and a Smartwatch, helped to overcome the limitation that smart devices have only single haptic actuator.

We explore the use of a head-mounted display to enhance social interaction by helping people with visual impairments align their head towards a conversation partner as well as maintain personal space during a conversation. Audio feedback is provided to the users guiding them to achieve effective face-to-face communication. A qualitative study of this method shows the effectiveness of the application and explains how it helps visually impaired people to perceive non-verbal cues and feel more engaged and assertive in social interactions.

# ACKNOWLEDGEMENTS

First of all I thank God Almighty for all his blessings throughout my life. I feel grateful to thank my advisor, Dr.Eelke Folmer for his constant guidance, support and encouragement which made it possible to complete this research. I would also like to thank the members of my committee Dr. Kostas Alexis and Dr. Fang Jiang. My lab mates Majeed, Jiwan, Bill, Sam and Ilias were very supportive and helpful in many circumstances. I would like to thank them as well for creating a great work environment. Finally, I want to thank my father, my mother and my brother who always support me and believe in me.

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# CHAPTER 1

# INTRODUCTION

The estimated number of people taht are visually impaired in the world is 285 million, 39 million blind and 246 million having low vision; 65% of visually impaired people and 82% of all blind are 50 years and older [36]. The visually impaired people face many problems and barriers in their day to day life because of their difficulty to understand their surrounding environment. Variety of software and hardware assistive technologies that has eased their life across mobility, daily life, literacy and communication were developed. During ancient times, they always had to be dependent on a person. This situation was reformed to an extent with the introduction of assistive technologies in a later time period. An early criticism of assistive technology is that it is often prohibitively expensive [1]. The high cost is due to their small sales volume, expensive certification testing and the non-generalized nature of their functionality. With the beginning of the digital age, smartphones became very popular among people and also came with a lot of features within it. Smartphones feature various built-in accessibility features for users who are visually impaired, such as screen readers and voice enabled personal assistants. Expensive assistive technology, such as currency readers, which used to cost hundreds of dollars [5], have been replaced with free apps [3]. Smartphones are considered as a promising platform to develop low-cost assistive technology [15] and smartphone usage among visually impaired people has been increasing [10]. Wearable technology is the leading new innovation since smartphones. The possibilities of wearables in augmenting the quality of life of people are endless. Different categories of wearables which were introduced includes Smartwatches, Google glass, head mounted displays, smart jewelry, smart clothing and the list is further increasing. At this point where digital world is influencing people‘s life,

Figure 1.1: a) Smartwatch b) Google Glass

this thesis explores the use of two wearable devices - Smartwatch and Google Glass (see Figure 1.1) to improve the life of visually impaired people.

The paper for FaceIT (Google glass application) research is to be submitted to CHI as an Extended Abstract in 2017 conference.

## 1.1 Smartwatch - Spatial haptic application

In recent years, Smartwatches have garnered significant public interest as it can interact in a more efficient, discreet, and non-obtrusive way than a Smartphone [44]. As blind people typically hold a cane or a leash to a guide-dog in one hand, access to computing from the wrist is more convenient and efficient than taking out a Smartphone. Smartwatches currently offer only a subset of functionality that is available on a Smartphone. In the future, Smartwatches could become the preferred mobile computing form factor, as visually impaired users have no use for increasingly larger Smartphone screens. To interact with mobile devices, blind people largely rely on audio, such as screen-readers. Offloading or supplementing the audio channel with haptic feedback is useful, especially in mobile contexts, which can be noisy while using a headphone. Audio feedback may be impeded by hearings sounds from the environment, such as car traffic. Smartphones typically feature a single haptic actuator. Because the skin is our largest organ, spatial haptic feedback significantly increases the amount of information that can be communicated. Various assistive systems that use spatial haptic feedback have been developed [23, 17, 50], but these typically rely on custom hardware, and are therefore not commercially available.

Because most Smartwatches are tethered to a smartphone for their mobile data needs, recent work has explored the concept of a joint interaction [19] between a smartphone and a Smartwatch to develop novel useful applications. These apps aren't accessible to individuals who are blind, but the proposed interaction concept has potential for developing low-cost assistive technology for blind users. The wrist is a more sensitive location for providing haptic feedback than a pocket [40]. Though recent Smartwatches (I-Watch) are capable of providing sophisticated forms of haptic feedback, they don't provide spatial feedback.

We present a novel navigation technique which assists visually impaired people to walk in a open space area without veering. We also explore providing spatial haptic feedback using a paired interaction between a Smartwatch and a smart device for achieving the above goal.

## 1.2 FaceIT

Human communication contains both verbal and nonverbal information, which interplay in our daily lives. Even a small and common conversation could contain a wealth of nonverbal information, which sighted people take for granted in daily routine. For example, a sighted speaker consciously and unconsciously uses eye contacts to convey information with the conversation partner [42]. This phenomenon where two people look at each other's eyes is mutual gaze[13]. Mutual gaze has important role in face-face conversation. Various researchers indicate different qualities that are exposed through high level of mutual gaze between two people. The qualities perceived by face to face communication with mutual eye gaze are intimacy, attentiveness, powerfulness and influential [45, 52, 8]. One among many problems faced by visually impaired people is the difficulty of eye gaze when talking to people during social gatherings. They need help from another person to orient themselves towards the conversation partner and to maintain personal distance from the partner. By performing an interview with eight visually impaired people, White et al.[49] found that one person has experienced the communication problem since it was difficult for him to meet people. He mentioned that this difficulty was that he could not see and make eye contact with the sighted people.

Eye contact being a key element in face-to-face conversation, FaceIT is a Google glass project that helps people who are blind in delivering an effective face to face communication by aligning their face to the conversing partner. This application is the very first application that helps the visually challenged person in a face-to-face communication scenario by overcoming his/her challenges in such a communication. The application finds the distance between the communicating partners. This information helps the user to maintain a social or personal distance while communicating. Hence, the application helps the visually impaired people to engage more in social activities. Another advantage of this application is the use of basic gestures available in Google Glass. The gestures being used are swipe left for information regarding face orientation, while swipe right gives information with respect to distance. All the information's is provided as audio feedback. The simpleness, understandability, accessibility and efficiency makes this application relevant in Human Computer Interaction.

The remaining of the thesis is organized as follows: Chapter 2 discusses the works with similar interests; Chapter 3 describes the design, methodology, implementation, user study and results for the spatial haptic application (smart watch application); Chapter 4 discusses the solution for face to face interaction for visually impaired people with essential design, user study and results; Chapter 5 concludes this thesis by discussing the limitation in each work and future modifications to make it more efficient.

# CHAPTER 2

# BACKGROUND AND RELATED WORK

## 2.1 Smartwatch - Spatial Haptic Application

Spatial haptic feedback has been explored for navigation, as a natural mapping that can be established between haptic cues on the body and geolocated information around the user.

### 2.1.1 Spatial Haptics for Navigation

GentleGuide [16] uses two wristbands with integrated vibrotactors. A user study with 16 sighted subjects found this approach to be useful for conveying indoor navigation directions. A vibrotactile belt [23] has been developed with 8 vibrotactors spaced 45° around the user. A user study with 12 sighted subjects found the belt to allow for accurately guiding a user towards a GPS coordinate. A similar approach uses a headband [17] to allow its wearer to have 180° spatial awareness from behind. 6 vibrotactors and infrared sensors were spaced 30° on the headband. A user study with 10 sighted subjects found 87% of subjects could avoid an unseen object from behind. SpaceSense[50] explores the use of vibration motors attached to different locations on a smartphone to convey spatial geographical information. A disadvantage of these approaches is that they have used custom hardware and none of the systems are commercially available. Lechal [4] is a commercially-available inset for shoes that connects to a smartphone using Bluetooth. This technique can be used for conveying navigation instructions, e.g., turn left or right by generating haptic feedback in either shoe.

### 2.1.2 Paired Interactions

Providing haptic feedback on different mobile devices (Smartwatch/smartphone) has been explored to convey different types of messages [40]. Duet [19] explored the design space of a joint interaction between a smartphone and a Smartwatch. Multi-device gestures, such as a pinch across devices, as well as using sensing information from the watch (orientation) were explored to create email and map applications. The design space is mapped by identifying what role each device plays, e.g., a device can be on the foreground or background. Most closely related to our approach is VI-Bros [35], which uses a smartphone and a Smartwatch to convey navigation directions in an indoor environment, similar to GentleGuide [16]. A number of holding positions are explored for the smartphone (pocket/hand). A user study with 3 sighted subjects demonstrated the feasibility of this technique to convey indoor navigation directions. None of these approaches report results and experiences with blind users.

### 2.1.3 Spatialized Haptic Feedback at the Wrists

Initially, studies were conducted to identify the best locations in the body where vibrations can be effectively felt. Fingers were often used for vibrotactile feedback due to their sensitivity to small amplitude and high spatial acuity. [22] Later studies were extended to examine the efficiency of sensing vibrational feedback to forearm and abdomen [20][21]. The results showed that performance is enhanced at points such as wrists, elbow and shoulder. Later studies showed that the performance of sensing the vibrations was slightly better at tactors located near the wrist than proximal to elbow[18]. The easiness to perceive alerts by those using wrist Worn Tactile Displays [WTDs] has been explored in various papers as well. Buzzwear[33] explored this by performing an experiment which evaluates user's ability to distinguish 24 tactile patterns associated with 4 parameters - intensity, starting point, temporal pattern and direction. They proved the easiness in perceiving the patterns associated with the parameters by achieving an accuracy of 99.32% which shows that application of usage of Smartwatch for haptic feedback. Haptic feedbacks with strong intensity and temporal patterns were most easily perceivable among the 4 parameters. Qian also experimented with determining the efficacy of multi-parameter tactile icons and concluded that vibrational feedback with strong intensity, short duration and short intervals are recognized and interpreted in shorter time than other combination of parameters[41]. Both these papers prove easy alert perception of wrist mounted tactile displays which thereby enable implementation of multitasking friendly mobile user interfaces. Based on these findings, we were stimulated to use spatial haptic feedback with strong intensity and short intervals in Smartwatches to provide feedback to blind users.

### 2.1.4 Multi-device Assistive Technology

A few approaches have explored creating assistive technology for blind users using multiple devices. Perkinput [12] is an input technique that uses two smartphone screens to provide Braille input. One hand provides input for dots 1-3 on one phone and dots 4-6 on the other in order to type a single character through chording. A wrist band was used to create a remote control for the iPhone for blind people [51]. In interviews, users expressed a desire to be included in wearable computing and expressed satisfaction with the multiple device setup. Gravvitas [26] attaches wearable vibrotactors on the index finger of both hands to let blind individuals trace lines on a map and diagram. A user study with 6 sighted subjects evaluated the feasibility of this technique.

## 2.2 FaceIT

Google glass has been explored for enabling face to face interaction for visually impaired user. It takes into account face recognition and audio feedback, giving information about face alignment and distance. Assistive technology has been growing drastically in this digital age. It resulted in development of lot of ideas and applications that assists blind people in various occasions.

### 2.2.1 Image recognition application

Mattos [37] introduced an image processing technology for the visually impaired to locate the object. Also the system can be used for automatic recognition of the texts and images. Balas [14] suggested a new class of image features that is useful to the set of representational tools for face-recognition tasks. Thus improvising the ideas of image recognition introduced techniques for face recognition using computer vision. Komai [30] proposed a visual speech recognition (VSR), method to convert faces viewed from various directions into faces that are viewed from the front using Active Appearance Models (AAM). TactileFace is a face recognition application which provides a real time conversion of face images into tactile counterparts which helps the users to understand the face by touching the tactile reproduction [34]. Another set of wearable eye glasses allows visually impaired users to identify faces of people present in the social places and helps them to identify and interpret facial expressions, emotions and gestures [32].

### 2.2.2 Sensing Gaze behaviors

Researchers also tried to understand the importance of gaze behavior and expressions in a face to face communication and its outcome on visually challenged people. In his research on dyadic (two-person) conversations, Argyle studied that about 75% of the time people are listening coincides with gazing at the speaker [7]. Kendon suggested the importance of giving attention and avoiding looking at the conversation partner's face during a dyadic conversation. He reports its effect while communicating emotions or relationships and its significance in regulating the flow of conversation [29]. In recent years, researchers have advanced gaze based interfaces using eye tracking technology. Eyefeel and EyeChime are two communication interfaces developed by Asako and Yasuaki which help in augmenting the eye gaze information within a face to face communication environment. Eyefeel helps in converting and delivering the gaze of another person as tactile information whereas EyeChime generates and plays sound when the participants who is sitting in a around a table meets with each other's face or eyes [28]. Agency Glass is another scenario which helps to decrease the emotional workload of sighted people by simulating their eye gestures [39]. Both the abovementioned applications are supported for sighted people. There are other applications which help visually impaired people to build a gaze communication. E-gaze is one such application that is designed to help blind people to access and react to gaze signals from blind people. This project is very much similar to ours except for the fact that it involves an external hardware and doesn't take into account the situation when blind person can independently walk towards the user and talk to them by maintaining the interpersonal space. Rantala et.al introduced an eye glass that provides haptic feedbacks which uses gaze gestures for input. The glass has a vibrotactile actuator that provides gentle simulation to three locations on users head [43].

### 2.2.3 Sensing facial expressions

Yet another research area which is an extension of face recognition in social interaction is to read the facial expressions during face-to-face communications. These are the visual cues which blind people are not able to access. Some applications related to this area are as below. Facial Expression Appearance vibroTactile System (FEATS) is a vibrotactile chair with 9 vibrators spatially mounted behind the chair [48]. These vibrators are used to convey some specific facial features. Another assistive technology was developed by Sreekar Krishna et al. using a vibrotactile glove with 14 tactors which is worn by the person who is blind. This glove conveys the conversation partner′s seven facial expression with different vibration patterns[31]. Douglas et al. has developed a face recognition system mounted on the white cane which can detect six basic emotions [9]. iFEPS also helps the visually impaired person to perceive his conversation partner′s facial expressions using a smartphone [47]. ABBI was proposed by Sara Finocchietti et al., which uses an audio bracelet to rehabilitate special cognition on how and where the body is moving which helps a blind person to conduct social interaction [25]. Expression is an application which uses Google Glass in order to track the face and detect the expressions in the face [6]. They detect up to 8 expressions including smile and yawn.

### 2.2.4 Interpersonal distance sensing

For over four decades, the effect of interpersonal distances in social situations have been studied in behavioral psychology. Proxemics distances vary with culture and environment. In a social interaction maintaining the interpersonal distance is very much important as mutual gaze and reading the expression. This is also an area which visually impaired people have difficulty. In order to convey interpersonal distance to visually challenged people there is another set of applications. McDaniel et al. uses an elastic vibrotatctile belt which has 7 tactors in order to help detect and localize people and objects in front of the user [38]. Another approach called Social Sensing designs a Wi-Fi signal based system to help the user to determine the presence of people and distance to people in the room [27].

Being said all the existing assistive devices examples, some of these application recognizes face, some of them in addition detects the facial expression and some other application helps to adjust the interpersonal distance. None of them had the combination of two most important factors which helps in starting the social interaction which are aligning face/gaze towards the conversing partner and maintaining the social interpersonal distance. FaceIT is a Google Glass application which guides the user to go near the person who is in nearby proximity and start talking to them by looking at them also maintaining proper social space. In this work, only interpersonal distances within personal distance (2.5 - 4 feet) is considered and we take into account one-to-one social interactions

# CHAPTER 3

# SMARTWATCH- SPATIAL HAPTIC APPLICATION

## 3.1 Motivational survey

Prior to the trials, we interviewed participants using non-directed questions to identify their interest in Smartwatches, and to verify whether the accessibility problems addressed by the app were real. Six out of seven participants owned a smartphone. In addition to calling and texting, most participants used their smartphone for email, playing games, taking notes and listening to audio books and podcasts. Five participants used their smartphone for navigation using apps such as, Google Maps, BlindSquare, and talking GPS. Six participants said crossing large open spaces was a problem. Strategies used to traverse open spaces include: (1) follow the edges; (2) follow a stranger; (3) rely on a sighted guide; and (4) use a GPS app.

Three participants used haptic feedback on their smartphone, mostly for notification. One participant used Morse code like vibration patterns to distinguish text messages from different people. None of the participants owned a Smartwatch, but four participants were open to buying one in the near future. Reasons for this included: (1) to replace their smartphone; (2) to answer their phone quicker; and (3) to use it for navigation.

## 3.2 Implementation

Conveying navigation directions using haptic feedback is useful for blind pedestrians [11]. Usually blind people rely on the tactile landmarks they encounter and they make a spatial map of the area in their mind. This mental map is essential for blind people to stay on the right track. Large open spaces, such as public squares, are often devoid of any tactile features. Following directions, such as crossing an open space, can be quite a challenge, and blind users often end up veering from their intended path [24]. We developed an app that guides blind users towards a specific destination. The spatial haptic feedback provision was inspired by how rumble strips work. These raised markers or notches in the road provide a tactile sensation to a driver when they drift from their lane and intuitively drivers steer away from the side of the car the haptic feedback was felt from. Blind users wear the Smartwatch on a wrist and the smartphone in their pocket or hand on the opposite side. Haptic feedback is provided in either of the devices depending on to which side the user is veering (asynchronous feedback) (See Figure 3.1).

This app uses Google Maps as a spatial data source. In this application user is provided with the option to select the destination point. User's starting point is chosen as the current location of the user when the destination location is selected. The orientation sensor and GPS are used to acquire the Azimuth values of the phone's current orientation ($\phi$) and direction ($\theta$) to the target. For better understanding consider a circle drawn around the user. The circle is divided into 8 segments of $45^\circ$ each. If both $\phi$ and $\theta$ are angles within the same segment it shows user is moving in the right intended direction. Phone's current orientation is updated every 5 seconds to keep the track of the user accurately. At any time if $\phi$ goes outside the segment of $\theta$ it means the user has veered from the proper path. If $\phi$

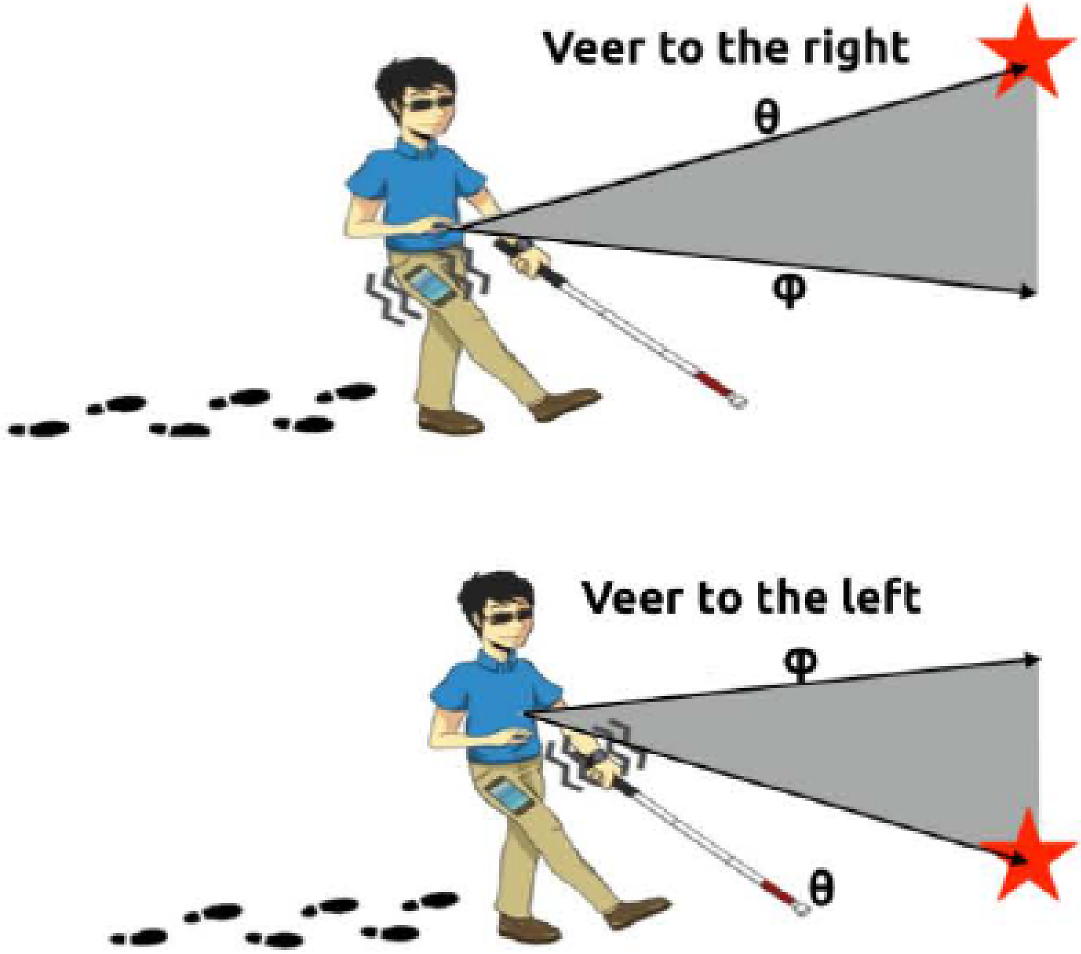


Figure 3.1: Rumble strips metaphor inspired the haptic feedback provision for the navigation app. If we detect the user is veering to the right, haptic feedback is provided on the right side (smart phone). If the user veers to the left haptic feedback is provided using the Smartwatch on their left wrist.

is now in the segment which is to the left(right) of $\theta$, it means the user has veered to left(right) direction. Similar to rumble strips, if the app detects the user veering to a side, haptic feedback on that side is provided to nudge a blind user to rotate away from the side the haptic feedback is felt from. One of the challenge faced was to determine in which hand each device should be placed. To allow hands-free usage, we intended to have users wear a phone in their pocket. Preliminary trials, however, found that subjects found it difficult to accurately feel haptic feedback when the phone was in their pocket. We believe to a large extent this depends on the type of pants and the fabric they are made of. For perceiving the haptic feedback perfectly, the users were advised to hold the phone in their hands. With the help of initial questionnaire, we found that majority of the users holds cane on their left hand. Users were instructed to wear Smartwatch on the right hand and hold the phone in the left hand considering the difficulty of holding the cane and mobile in the same hand. When user veer to left side Smartphone provides haptic feedback whereas when the user veers to right direction Smartwatch provides haptic feedback. The spatial haptic feedback provided is asynchronous. This type of functionality would be difficult to provide using a single smartphone, as users would not know what direction to turn to when they veer. Alternatively, the target direction could be indicated using haptic feedback, but for long traversals this would drain the battery and users' hands might start feeling numb. Haptic feedback was produced constantly for a period of 70ms until the user is facing to the correct path. When the user is less than 7 meter away from the destination point, they are notified by a speech.

## 3.3 Methodolgy

### 3.3.1 Participants

Seven blind participants were recruited from a local chapter of the National Federation of the Blind (3 Female and 4 males, average age 38.3, SD = 12.5). Three participants were totally blind and four participants were legally blind with some

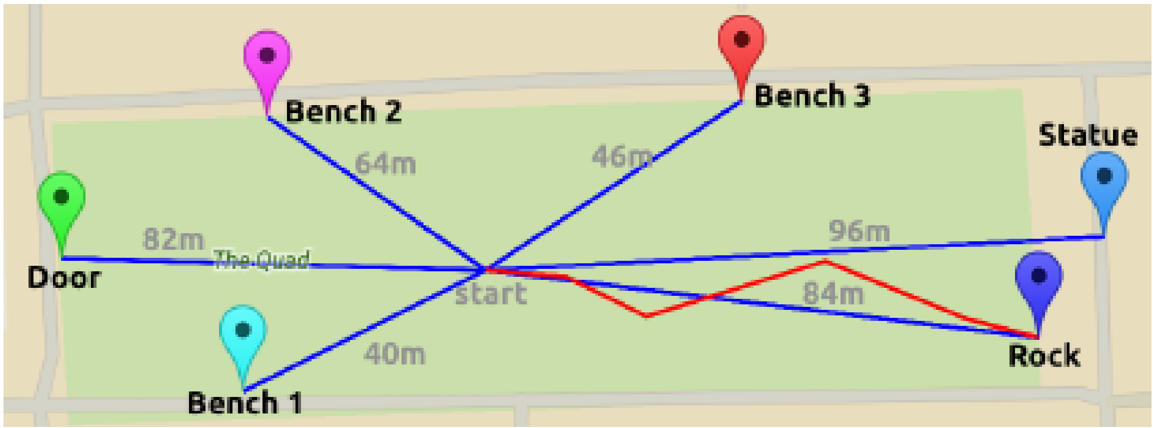


Figure 3.2: Map of the quad, showing the six target destinations. Distance in grey. The red line shows an actual path followed by a participant.

residual light perception. The legally blind participants wore a blindfold during the user studies. None had any self-reported impairments in mobility or tactile perception. All participants were right-handed and used a cane for navigation.

### 3.3.2 Apparatus

To implement this app, we used an Android Nexus 5 smartphone with a Qualcomm Snapdragon 800 CPU (2.3 GHz quad-core) running Android Lollipop 5.1. We used the Samsung Gear Live Smartwatch running Android Wear 5.0.2. The Smartwatch was connected to the smartphone using Bluetooth. A helper app on the Smartwatch created using Android Wear receives messages from the smartphone app to enable or disable haptic feedback. Though haptic actuators are subject to a startup delay this did not seem noticeable.

### 3.3.3 Design

A within subject user study was performed to collect the quantitative and qualitative analysis of the Smartwatch application. This application relies mostly on the starting and destination GPS coordinates. Since the GPS accuracy varies from 5-8.5 meters depending on the weather conditions, atmospheric effects, multipath effect, satellite geometry etc. [2], it is considered as a confounding variable throughout the study. The starting point is kept as constant for all the participants whereas the destination location is randomly chosen from the list of locations. Destination location is the independent variable in this user study which helps us to examine the path used by the user to reach the destination. We use six different destination location which are of varying distance and varying direction from the starting location (see Figure 3.2). This is to test the efficiency and effectiveness of the application. While performing each test case, the no: of times the user veered is measured along with the total time they took to reach the destination. After completion of all the six test cases, users were also asked to perform qualitative analysis by rating the usability, learnability, reliability and understandability of the application using a 5-point Likert scale (1- Strongly disagree to 5-Strongly agree)

### 3.3.4 Procedure

The user study was conducted in a large open grass area (150 x 50 meters) called the Quad. Six distinct destinations were defined (see Figure 3.2) as well as a starting location. Participants wore a Smartwatch on their right wrist and held the phone in their left hand (see Figure 3.3). Participants were instructed how to interpret the haptic feedback using the rumble strips metaphor. They were told to

Figure 3.3: A participant taking part in user study

walk in the direction they were facing if no haptic was felt and turn away from the side haptic feedback was felt from until feedback stopped. Participants tried out a single path. When they felt comfortable, the trial started. The order of paths was randomized and the quad was free of obstacles. Participants were not told what their destination was, but to just follow the haptic guidance. GPS has an accuracy that varies between 5 and 8.5 meters [53]. The app considered the navigation task a success if the user was within 7 meter of the destination, which was verbally announced to the user. After that participants were returned to the start location and the next path was started.

| | **Guided Navigation** | | | | | | |
|---|---|---|---|---|---|---|---|
| **P** | **Statue** | **Stone** | **Bench 1** | **Door** | **Bench 2** | **Bench 3** | **Avg no: of time feedback received** |
| 1 | 128 | 143 | 154 | 108 | 107 | 104 | 15 |
| 2 | 133 | 104 | - | 123 | 93 | 55 | 8 |
| 3 | 98 | 70 | 70 | 99 | 72 | 40 | 6 |
| 4 | 192 | 128 | 43 | 114 | 90 | 54 | 9 |
| 5 | 202 | 94 | 47 | 103 | 107 | 51 | 8 |
| 6 | 148 | 237 | 189 | 181 | 94 | 85 | 11 |
| 7 | 186 | 112 | 46 | 95 | 202 | 94 | 10 |
| Avg | 155 | 127 | 92 | 118 | 109 | 69 | 9.44 |
| SD | 39 | 54 | 64 | 30 | 42 | 25 | 2.74 |

Table 3.1: Guided navigation: results for each path in seconds and average number of feedback received for successful completion of each test case

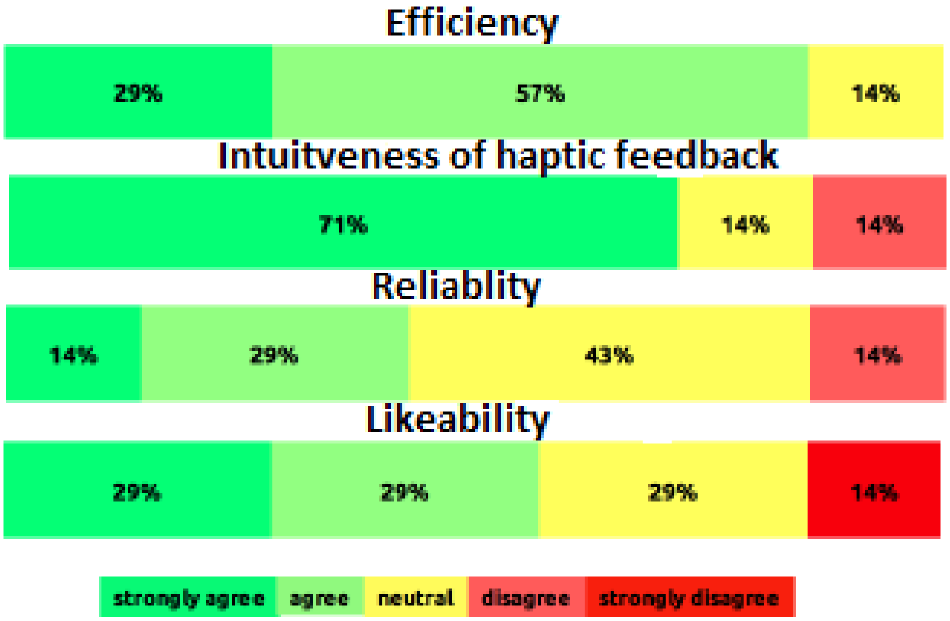


Figure 3.4: Qualitiative responses on the usability of the app.

## 3.4 Results

Table 3.1 lists the results for each participant. All but one participant (P2) was able to successfully navigate to each destination. Due to a temporary obstruction (sprinkler leak) we were not able to let P2 navigate to bench1. The average navigation times vary between each path due to the varying distances. The average no:

of feedback received by all the users are also shown in table 3.1. It is seen that all 6 out of 7 participants reached their destination with an average no: of feedback less than 12. One person who has an average of 15 had a difficulty in feeling the haptic feedback as and when it occurred. Figure 3.4 shows the qualitative analysis of the application. Most of the users agreed to the effectiveness of the applications and intuitiveness of haptic feedback. Quite a number of percentage is shown as neutral. Since the users are visually impaired they might have felt they made errors while using the application based on the number of haptic feedback's they sensed or at times they were confused to which direction they should turn to. As they reached 6th test case, every user seemed to complete the task very quickly with least number of feedbacks.

## 3.5 Discussion

The app was perceived positively, however, P3 strongly disliked the navigation app despite having average results. When asked about this P3 said: *"I just don't like haptic feedback"*. Individual preferences aside, most participants thought the app was useful and the haptic feedback provision that was used was perceived as intuitive.

An interesting issue that was raised when we designed the navigation app was on what arm a blind person should wear their Smartwatch. Most people wear a Smartwatch on their non-dominant arm, as their dominant hand is more dexterous and which facilitates input provision, however, blind people typically hold a cane or a leash in their dominant arm. For them it would be more practical to wear the Smartwatch on their dominant arm, to allow them to interact with their watch without having to put the cane or leash away. P6 however said that he used his right arm to get feedback from his cane and it was therefore difficult to pay close attention to receiving feedback from the watch.

# CHAPTER 4

# FACEIT

## 4.1 Motivational survey

We conducted an online survey for visually impaired people where they were asked to answer some in-directed questions. This helped to identify the accessibility problems they were facing during communications in social occasions and their approach to these problem.

From the feedback, the main difficulties they mentioned included not being able to face the speaker, people walking around without saying anything, recognizing a person, their facial expressions and body language, approaching different people and starting talking with them and maintaining the eye contact. They all agreed to the importance of facing a conversation partner. More than 50% of the people agreed they had difficulty in facing their conversation partner and maintaining correct distance from them. The solution which all the visually impaired people stated was to listen to the sound of the voice and turn to that direction. FaceIT is an application which is a better approach that could be used by visually impaired people to confirm that they are facing the conversation partner by standing at the correct conversation distance.

## 4.2 Implementation

Social gatherings are one such place which everyone would like to go. Conversations are an essential part of social interactions and eye-gaze plays an important role as a non-verbal component of conversation. Simmel[46] has stated that "The totality of social relations of human beings, their self-assertions and self-abnegation, their intimacies and estrangements, would be changed in unpredictable ways if there occurred no glance of eye to eye". This statement justifies the significance of eye contact in conversation. Examining the situations that visually impaired people might deal with when they go to social gatherings, we found three situations. One situation is where one person is talking to you, second situation is where you are not sure if there are any person in the room and third situation is you are not sure about your distance with the conversation partner. Considering the first case, usually visually impaired person rely on sound waves to orient their head towards the conversation partner. The problem here is even though they can turn their head toward that side, still it might not be fully oriented with the partner. In the second situation there is nothing much a blind person can do as he/she is not aware if there is any person in the room. In the third situation, the other partner can adjust their distance by moving back or forth adjusting to the distance with visually impaired people but it can't be done vice versa. To address these issues we have developed an application FaceIT which will use Google glass (henceforth termed as glass) to provide voice feedback which gives information to the users about the presence of a person and the direction to align their head & distance with the partner. Figure 4.1 shows the system architecture of FaceIT. It has two modules: Data acquisition module and Data assessment & Feedback module.

In Data acquisition module, Glass camera is used to capture the camera frames (4-6 frames per second).The captured frames are then converted to grayscale for reducing the size of the frame. This is a client-server model where Glass acts as client and Windows PC system acts as server. The client- server model approach was followed as we observed heavy battery drain and high heat dissipation on

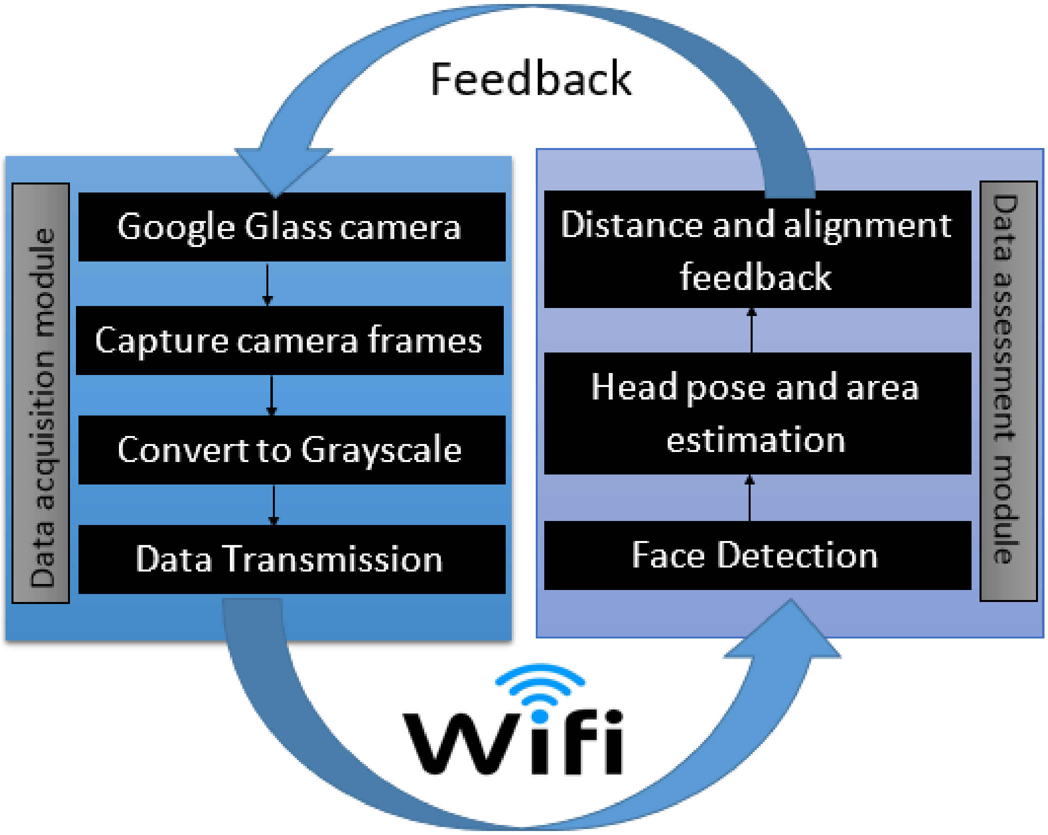


Figure 4.1: System architecture of FaceIT

running the application on the Glass. After converting, the frames are transmitted to the server through Wi-Fi network for data assessment and client waits for the feedback from server.

In Data assessment module, as the server receives the frames, face detection is performed using OpenCV face detection algorithm. When a face is detected in the frame, a flag is set to 1 and the entire frame is divided into 3 X 3 matrix. Further, application checks the position of the center of eyes within the frame i.e. within which block of 3 x 3 matrix does the center of eyes of the head lies (Figure 4.2). This position gives the alignment of head. Starting from row 1 and column

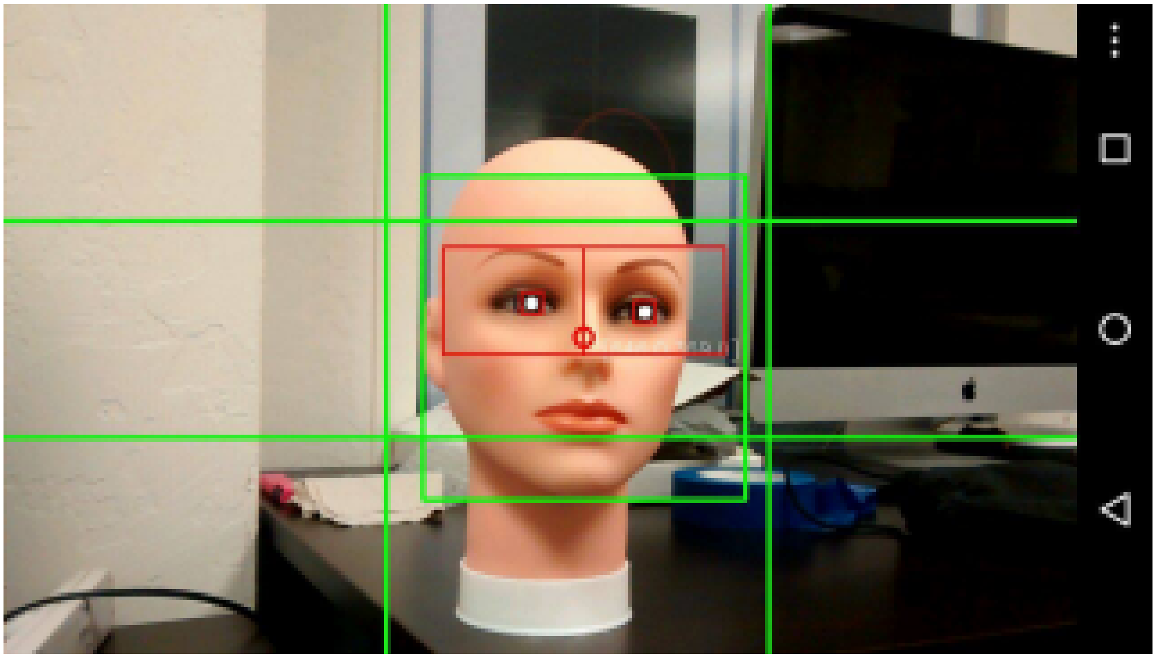


Figure 4.2: Face detection and dividing a frame into 3x3 matrix to find the position of center of eyes of head.

1 the cells in matrix are numbered from 0-8 in order i.e. (0,0) is 0, (0,1) is 1 and so on. This number is returned to the client. Further, server calculates the total area of the square which contains the head (henceforth termed as head-square). It is understood that when the user is far from the conversation partner, the partner's head will be encompassed in a small square and hence the area of the head-square will be small. As the user moves closer to the conversation partner the head-square will become larger and it may also go outside the frame when the user is too close. So the area of the square at any time is used as a parameter to calculate the distance between the user and conversation partner. The computed area is also returned to the client as feedback.

Hence, the feedback passed back to the client contains the flag value which shows the presence of the face in the frame which was transmitted to server, position of head which gives the alignment of head and area of the head-square which gives the distance from the head. Once these values are in the client, whenever the user interacts with the glass, they will be provided with respective feedbacks. In this application there are two interactions happening between user and the glass. User can swipe the glass touch-pad forwards and backwards. When user gives a forward swipe, based on the area value, he/she will get a voice feedback which could be ′far′, ′correct or ′close′. ′Far′ means that user is far from the opposite person and have to move one step closer, whereas ′close means the reversal. ′Correct′ means that user is in the right distance from his/her conversation partner. Similarly, when the user swipes backwards he/she will be given direction of how his/her face should be aligned so as to be facing his/her conversation partner. The possible voice feedback cases according to the returned position are as follows: 0-right up, 1-up, 2-left up, 3-right, 4-facing, 5-left, 6-right down, 7-down, 8-left down. User is required to move their face according to the obtained feedback.

## 4.3 Methodology

### 4.3.1 Participants

As this system is intended for visually impaired people, we chose 9 participants (3 males and 6 female) in which one participant is totally blind, 2 participants have low vision and rest of the participants were sighted people. They were made low vision by blindfolding their eyes. These participants have never used this application before. Their ages ranged between 20-40. Chosen participants had some knowledge with technology as all of them own a smart phone. This knowledge was essential since users had to work with gestures while using the experimental apparatus which is a Glass.

### 4.3.2 Apparatus

This project is developed on a Google Glass. Since the computation power of Glass is low the performance used to decrease over time. So a server which is running on PC was developed. During the user study users will be using only Google glass. All the back side work is done by the server without the user knowing about it. Server keeps track of everything that user sees and this log details can be used to evaluate the user study. So the hardware included in this application are a Google Glass and a PC with 64 bit Windows 7 Operating System. We are also using a dummy head replacing a real human since it was more convenient for testing purposes. The entire apparatus is shown in 4.3.

### 4.3.3 Design

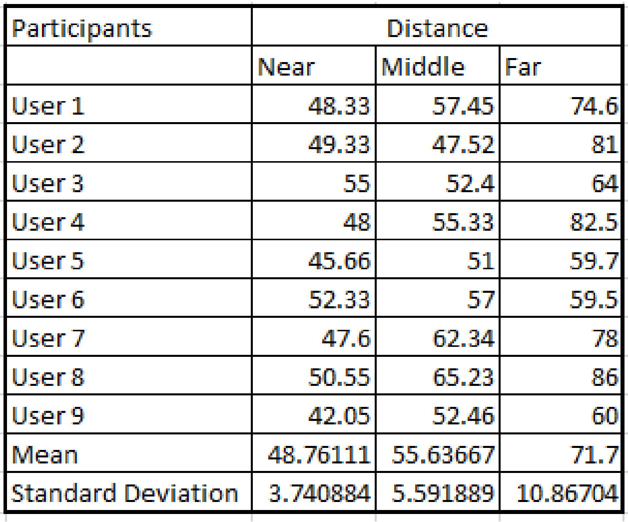
In this experiment, within subject study is performed to evaluate qualitative analysis by studying the efficiency, success rate, learnability, understandability and usability of the application. These values are measured with respect to three independent variables which are position of the dummy head, distance between dummy head and user and feedback provided. The levels of these independent variables are as follows: position of dummy head: right, left and center, distance between user and dummy head: far (4 feet), middle (3.5 feet), near(3 feet) and feedback provided: voice feedback. So in total 3x3x1 = 9 test cases are evaluated during the user study. During each test case the dependent variables which are

Figure 4.3: a) Google Glass b) Dummy head c) PC with server running on it

measured quantitatively are number of responses (includes number of forward swipes + number of backward swipes) by each participant in each test case, total time taken for the completion of each test case (End time - start time). Other dependent variables which are measured for qualitative analysis are the success rate (how far user was able to align their face with dummy head), efficiency, learnability, usability, understandability and reliability. Apart from the success rate which is measured manually, all other variables are evaluated with respect to the responses provided by the user using Likert scale (1-Strongly disagree to 5-Strongly agree) during post questionnaire. In total, design space is 9x3x3x2 = 162, where number of participants is 9, number of position independent variable is 3, number of distance independent variable is 3 and 2 is the number of data which contains task completion time as well as number of swipes by each user in each task). The total task completion time taken by each user for near, middle and far distances are mentioned in figure 4.4. The task completion time is measured in seconds.

### 4.3.4 Procedure

As the user is welcomed for the user study he/she is asked to fill a short pre-questionnaire which generally included demographic details and also to know their experience with technology. After filling out the pre-questionnaire, users where introduced to the application by giving instructions on how to use a Glass and how does the swipes gives feedback with respect to the application. Users will initially start the application by tapping twice. Once the application is started, users have to scan the space in front of them to detect the face. Once face is found the application says a voice feedback saying 'face found'. Once the face is found, user can interact with the Google glass to find the direction to which face should be aligned and to find their distance with the dummy head. The two main forms of interactions are swipe backward and swipe forward. When the user swipe backward it gives audio feedback about how to align the face. The possible feedbacks are up-left, left, up-right, right, down-left, down-right, down, up and facing. Based on these feedbacks the user should slightly move their face in those directions. The second form of interaction i.e. swipe forward gives the distance from the dummy head. It gives possible auditory feedbacks as too far, far, correct, close and too close. Based on this feedback the user should adjust their distance. Once it says facing when swiped backwards and correct when swiped forwards it means that user is facing the person and is at a correct conversation distance. Then the appli-



| Participants | Distance | | |
|---|---|---|---|
| | Near | Middle | Far |
| User 1 | 48.33 | 57.45 | 74.6 |
| User 2 | 49.33 | 47.52 | 81 |
| User 3 | 55 | 52.4 | 64 |
| User 4 | 48 | 55.33 | 82.5 |
| User 5 | 45.66 | 51 | 59.7 |
| User 6 | 52.33 | 57 | 59.5 |
| User 7 | 47.6 | 62.34 | 78 |
| User 8 | 50.55 | 65.23 | 86 |
| User 9 | 42.05 | 52.46 | 60 |
| Mean | 48.76111 | 55.63667 | 71.7 |
| Standard Deviation | 3.740884 | 5.591889 | 10.86704 |

Figure 4.4: Data used for simulation

cation is ended by swiping down. Users are made to do 2 trial runs so that they get to understand the interactions and feedback much better. Later, real experiment is done with the 9 test cases mentioned above. After completing all 9 test cases, user is asked to fill a post questionnaire which performs qualitative analysis of the application using Likert Scale.

## 4.4 Results

Both quantitative and qualitative evaluation was performed to illustrate the utility of the application. Overall accuracy of the application was high as 98% as all the users were able to align their head with respect to the dummy head correctly. Anova is used to evaluate the significance of task completion time with respect to two independent variables which are position of the dummy head and distance between the user and the dummy head. There was significant effect of distance with task completion time (F(2, 16) = 24.396 and p= 0.0001). Since p value is less than

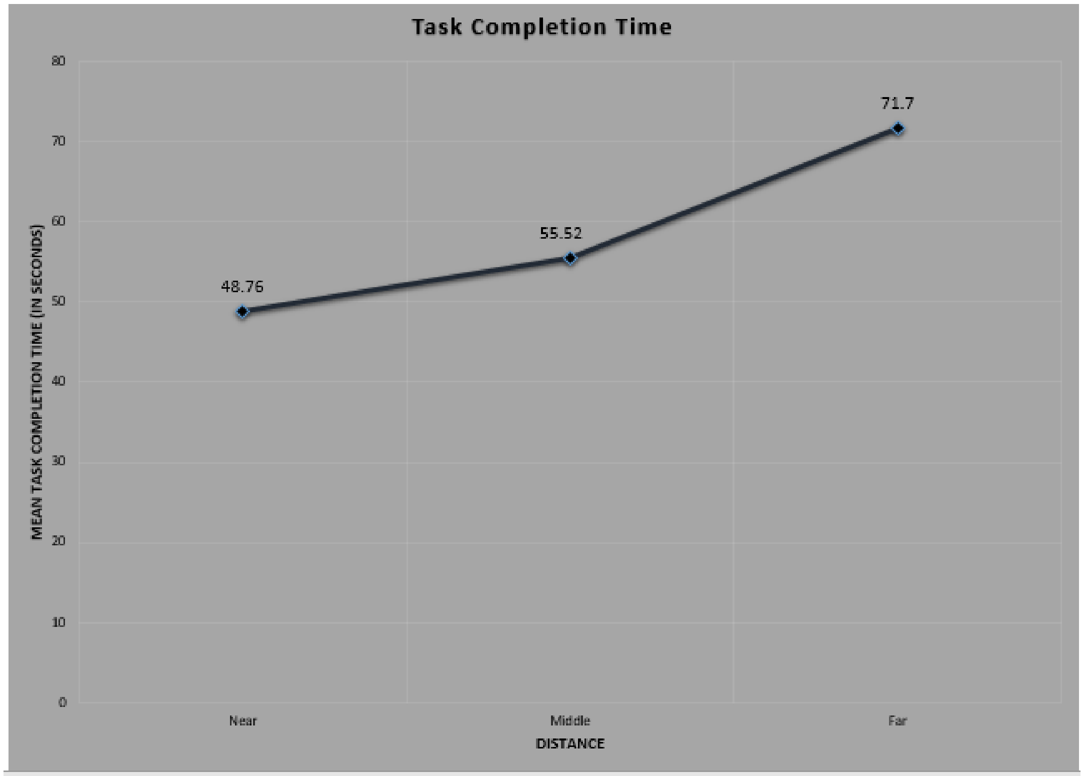


Figure 4.5: Graph shows task completion time depends on distance

0.0005, task completion time is significant based on the distance of the user from the dummy head rather than position of the user (F(2, 16) = 0.836 and p = 0.4572 >0.005). As the distance increased or decreased, the task completion time also increased or decreased respectively. The mean task completion time for 9 tasks with respect to distance is 48.76, 55.63, 71.7 for near, middle and far respectively (figure 4.4). It is clearly observed from the mean that as distance is increased the task completion time increases and graph representation for the same is shown in figure 4.5. Irrespective of the position's where the users stood, users where able to align their head properly with the dummy head. It is understood from the task completion time which was captured for all nine tasks that after each task the users was getting more familiar with the application and the task completion time decreased as they complete each task successfully. Qualitative analysis was performed using a

5-point Likert scale with 1 being strongly disagree and 5 being Strongly agree. Figure 4.6 shows the qualitative evaluation result. Reliability was measured by asking the users if they felt they made any errors. This is bit low because it took time for users to get adapted to the feedback. During the first stages when they receive the feedback 'left' they turned their head too much left which resulted in missing the frame with face. So in this way errors were made by the users which got corrected by itself with the successful completion of each task. Overall, the users liked the application and its learnability and usability very well. In terms of suggestion and improvement one user said that he didn't have any idea regarding the distance between user and the dummy head and so any initial value which could give a rough distance between the user and dummy head would be good to have an idea about the distance. One user suggested that the starting felt bit lagging and having an initial voice feedback saying the application is started will be useful. Another user wanted continuous feedback until she reached the correct position so that she don't have to swipe all the time. Two participants liked the purpose of the application and agreed that this will be very useful for blind people.

## 4.5 Discussion

The focus of this research was to help visually impaired people to orient their head with their conversation partner. All the users were able to successfully complete this task. We discussed about relation between task completion time and distance in the result. But there is further more to discuss which is number of swipes.

Number of swipes of given by the participants is also relevant because certain pattern was observed which affected the task completion time. Certain partici-

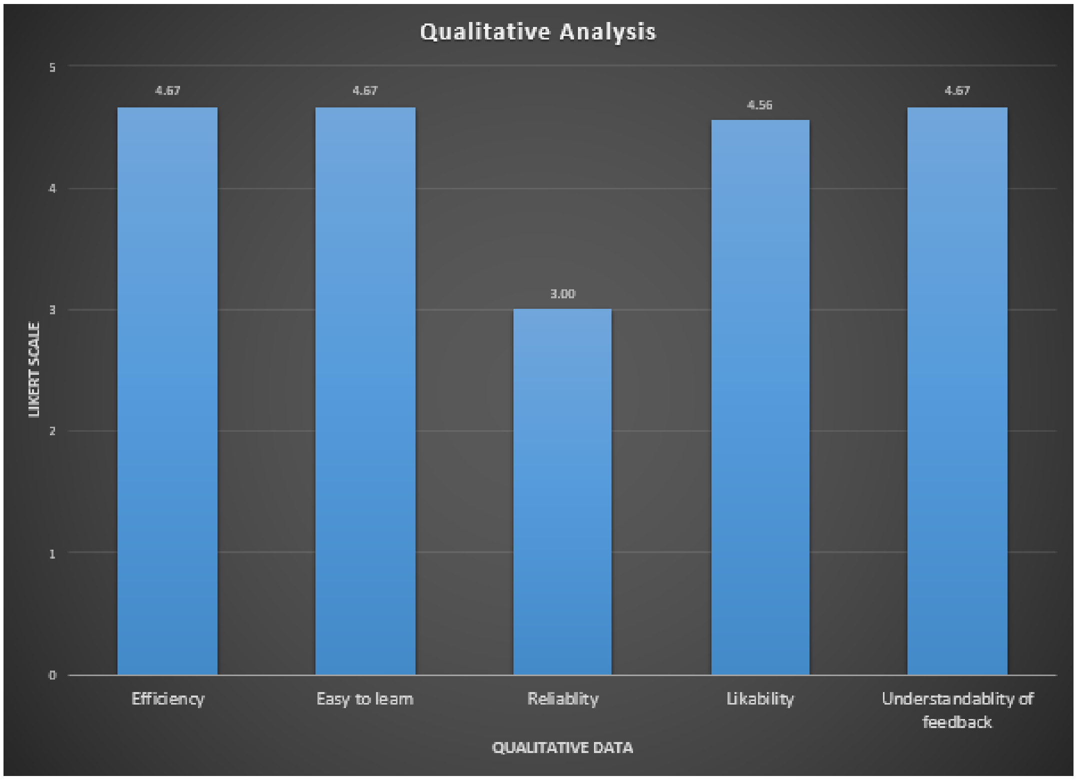


Figure 4.6: Graph showing qualitative evaluation

pants used less number of swipes to complete the task and certain participants used more number of swipes. Also participants were asked to do forward swipe and backward swipe according to their interest. Five out of seven participants used forward swipe first and then backward swipe. This increased the task completion time by an average of 30 seconds because when they are adjusting their distance by doing forward swipe and there is high chance they might go out of the frame where dummy head is placed. When this happens application gives a voice feedback saying 'Face not found'. Then they need to scan the environment again to find a frame with head in it and again do swipes. Whereas one of the participant used backward swipe first which was followed by forward swipe. So by doing this he tried to align his face correctly with the dummy head first and then correct the distance between them. Hence by doing this he has lesser chance to go out of the frame compared to other. Another participant used backward and forward swipes alternatively. So he made sure he is never out of the frame which contains head because he was correcting his head orientation and distance equally. This was observed to take the least task completion time compared to other both.

Furthermore, the distance at which Glass was able to detect face was a problem. Due to its low resolution camera, Glass can detect a face only at a distance of 4.1 feet. This could be further explored to find ways which would allow the users to detect the face irrespective of distance.

We found that Wi-Fi signal strength is also an important factor which increases or decreases the speed at which frames are sent from client to server. When Wi-Fi strength is at its highest the round trip time was found to be less than 100ms. Whereas when the strength is low, it takes near to 1 minute as round trip time. We ensured consistency of Wi-Fi strength during the user study by maintaining high Wi-Fi strength throughout.

There were some issues of background face detection as well where the application was detecting some objects which has the shape of face (e.g. square shaped small speaker box). This problem could also be further explored to overcome this issue.

# CHAPTER 5

# CONCLUSION

### 5.0.1 Summary

The main idea behind exploring wearable technology was to help visually impaired people to understand their surroundings in a better way. Spatial haptic application is a novel approach of using a Smartwatch and a Smartphone working as PairABLE's to guide visually impaired people to navigation in open spaces. Overall, we demonstrated the feasibility of using a paired interaction for developing low-cost spatial haptic app. Though Smartwatches cost a few hundred dollars, the efficient, non-obtrusive interaction they offer specifically benefits users who are blind, as they have no need for large screens. With smartphone adoption being high among blind users [10], Smartwatch usage could eventually be high too, which would reduce the cost of spatial haptic feedback provision to $0, especially considering that few systems are commercially available.

Also, FaceIT application implemented in Google Glass helped visually impaired people to know their surrounding in a social occasion. Basically we have addressed all the three problems pointed out in the implementation section. With the help of this application, user can orient their head towards the conversation partner if someone comes to talk with them, user can adjust their distance thus maintaining the personal space and also if the user is not aware about presence of people in a room, he/she can scan the room with the help of Google Glass which will return a voice feedback when a human face is found thus assures the presence of human inside the room. The implementation and good results signifies the effectiveness and usability of the application.

### 5.0.2 Future Work

As future work of Smartwatch application, we will investigate using an iWatch, which features a linear resonant actuation (LRA) that is capable of providing much stronger haptic sensations, such as tapping. Building on the concept of a paired interaction to create low cost assistive technology, we will explore useful apps for other types of impairments. For example, a Smartwatch could function as a switch input controller for interacting with a head-mounted display, which could be useful for someone who is quadriplegic. It may be challenging for wheelchair users to look under a couch or table when looking for a lost item and they often rely on low-cost technology like a mirror on a stick. A periscope like app could channel the smartphone camera to the Smartwatch screen, and a wheelchair user can look into locations out of their sight with the smartphone attached to a selfie stick.

In FaceIT application, the current study provides a starting point for the exploration of face at any distance and at any angle. Better face detection algorithms could also be tested or new ones could be explored to reduce the problem of background face detection. This application could be extended to other head mounted devices which could be cheaper than Google Glass but have higher efficiency. Nonverbal cues given by conversation partner could also be incorporated in this application to increase its effectiveness. The application could also be expanded to detect expressions and body language as well.

# BIBLIOGRAPHY

[1] Technology helps disabled people, but is expensive, global accessibility news, `http://globalaccessibilitynews.com/2011/03/08/`, March 2011.

[2] Gps global positioning system - montana state university, `http://www.montana.edu/gps/slides/2gpsaccuracy.pdf`, August 2015.

[3] Ideal currency identifier, `https://play.google.com/store/apps/details?id=org.ideal.currencyid&hl=en`, August 2015.

[4] Lechal: Haptic footwear, `http://lechal.com`, August 2015.

[5] Note teller 2, `http://www.brytech.com/noteteller/`, August 2015.

[6] ASM Iftekhar Anam, Shahinur Alam, and Mohammed Yeasin. Expression: A dyadic conversation aid using google glass for people who are blind or visually impaired. In *Mobile Computing, Applications and Services (MobiCASE), 2014 6th International Conference on*, pages 57–64. IEEE, 2014.

[7] Michael Argyle. The psychology of interpersonal behavior. Technical report, 1972.

[8] Michael Argyle, Luc Lefebvre, and Mark Cook. The meaning of five patterns of gaze. *European journal of social psychology*, 4(2):125–136, 1974.

[9] Douglas Astler, Harrison Chau, Kailin Hsu, Alvin Hua, Andrew Kannan, Lydia Lei, Melissa Nathanson, Esmaeel Paryavi, Michelle Rosen, Hayato Unno, et al. Increased accessibility to nonverbal communication through facial and expression recognition technologies for blind/visually impaired subjects. In *The proceedings of the 13th international ACM SIGACCESS conference on Computers and accessibility*, pages 259–260. ACM, 2011.

[10] Jonathan Avila. Trends in mobile device use by people with disabilities, `http://www.accessiq.org/news/features/2014/03/trends-in-mobile-device-use-by-people-with-disabilities`, March 2014.

[11] Shiri Azenkot, Richard E Ladner, and Jacob O Wobbrock. Smartphone haptic feedback for nonvisual wayfinding. In *The proceedings of the 13th international ACM SIGACCESS conference on Computers and accessibility*, pages 281–282. ACM, 2011.

[12] Shiri Azenkot, Jacob O. Wobbrock, Sanjana Prasain, and Richard E. Ladner. Input finger detection for nonvisual touch screen text entry in perkinput. In *Proceedings of Graphics Interface 2012*, GI '12, pages 121–129, Toronto, Ont., Canada, Canada, 2012. Canadian Information Processing Society.

[13] Jeremy N Bailenson, Jim Blascovich, Andrew C Beall, and Jack M Loomis. Equilibrium theory revisited: Mutual gaze and personal space in virtual environments. *Presence*, 10(6):583–598, 2001.

[14] Benjamin J Balas and Pawan Sinha. Region-based representations for face recognition. *ACM Transactions on Applied Perception (TAP)*, 3(4):354–375, 2006.

[15] Nick Bilton. New york times blog. disruptions: Visually impaired turn to smartphones to see their world, `http://bits.blogs.nytimes.com/2013/09/29/disruptions-guided-by-touch-screens-blind-turn-to-smartphones-for-sight/`, September 2013.

[16] Sal Bosman, Bas Groenendaal, Jan-Willem Findlater, Thomas Visser, Mark de Graaf, and Panos Markopoulos. Gentleguide: An exploration of haptic output for indoors pedestrian guidance. In *Human-computer interaction with mobile devices and services*, pages 358–362. Springer, 2003.

[17] Alvaro Cassinelli, Carson Reynolds, and Masatoshi Ishikawa. Augmenting spatial awareness with haptic radar. In *Wearable Computers, 2006 10th IEEE International Symposium on*, pages 61–64. IEEE, 2006.

[18] Hsiang-Yu Chen, Joseph Santos, Matthew Graves, Kwangtaek Kim, and Hong Z Tan. Tactor localization at the wrist. In *Haptics: Perception, Devices and Scenarios*, pages 209–218. Springer, 2008.

[19] Xiang 'Anthony' Chen, Tovi Grossman, Daniel J. Wigdor, and George Fitzmaurice. Duet: Exploring joint interactions on a smart phone and a smart watch. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, CHI '14, pages 159–168, New York, NY, USA, 2014. ACM.

[20] Roger W. Cholewiak, J. Christopher Brill, and Anja Schwab. Vibrotactile localization on the abdomen: Effects of place and space. *Perception & Psychophysics*, 66(6):970–987.

[21] Roger W. Cholewiak and Amy A. Collins. Vibrotactile localization on the arm: Effects of place, space, and age. *Perception & Psychophysics*, 65(7):1058–1077.

[22] James C Craig and Carl E Sherrick. 6. dynamic tactile displays. *Tactual perception: A sourcebook*, page 209, 1982.

[23] Jan B. F. Van Erp, Hendrik A. H. C. Van Veen, Chris Jansen, and Trevor Dobbins. Waypoint navigation with a vibrotactile waist belt. *ACM Trans. Appl. Percept.*, 2(2):106–117, 2005.

[24] Alexander Fiannaca, Ilias Apostolopoulous, and Eelke Folmer. Headlock: A wearable navigation aid that helps blind cane users traverse large open spaces. In *Proceedings of the 16th International ACM SIGACCESS Conference on Computers & Accessibility (ASSETS)*, pages 19–26, New York, NY, USA, 2014. ACM.

[25] Sara Finocchietti, Giulia Cappagli, Gabriel Baud-Bovy, Charlotte Magnusson, Hector Caltenco, Graham Wilson, Stephen Brewster, Ann-Kathrin Rogge, Brigitte Röder, Elena Cocchi, et al. Abbi, a new technology for sensory-motor rehabilitation of visual impaired people. 2015.

[26] Cagatay Goncu and Kim Marriott. Gravvitas: Generic multi-touch presentation of accessible graphics. In *Proceedings of the 13th IFIP TC 13 International Conference on Human-computer Interaction - Volume Part I*, INTERACT'11, pages 30–48, Berlin, Heidelberg, 2011. Springer-Verlag.

[27] Yoni Halperin, Galit Buchs, Shachar Maidenbaum, Maya Amenou, and Amir Amedi. Social sensing: A wi-fi based social sense for perceiving the surrounding people. In *Proceedings of the 7th Augmented Human International Conference 2016*, AH '16, pages 42:1–42:2, New York, NY, USA, 2016. ACM.

[28] Asako Hosobori and Yasuaki Kakehi. Eyefeel &#38; eyechime: A face to face communication environment by augmenting eye gaze information. In *Proceedings of the 5th Augmented Human International Conference*, AH '14, pages 7:1–7:4, New York, NY, USA, 2014. ACM.

[29] Adam Kendon. Some functions of gaze-direction in social interaction. *Acta psychologica*, 26:22–63, 1967.

[30] Yuto Komai, Nan Yang, Tetsuya Takiguchi, and Yasuo Ariki. Robust aam-based audio-visual speech recognition against face direction changes. In *Proceedings of the 20th ACM international conference on Multimedia*, pages 1161–1164. ACM, 2012.

[31] Sreekar Krishna, Shantanu Bala, Troy McDaniel, Stephen McGuire, and

Sethuraman Panchanathan. Vibroglove: an assistive technology aid for conveying facial expressions. In *CHI'10 Extended Abstracts on Human Factors in Computing Systems*, pages 3637–3642. ACM, 2010.

[32] Sreekar Krishna, Greg Little, John Black, and Sethuraman Panchanathan. A wearable face recognition system for individuals with visual impairments. In *Proceedings of the 7th international ACM SIGACCESS conference on Computers and accessibility*, pages 106–113. ACM, 2005.

[33] Seungyon "Claire" Lee and Thad Starner. Buzzwear: Alert perception in wearable tactile displays on the wrist. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, CHI '10, pages 433–442, New York, NY, USA, 2010. ACM.

[34] Nan Li, Zheshen Wang, Jesus Yuriar, and Baoxin Li. Tactileface: a system for enabling access to face photos by visually-impaired people. In *Proceedings of the 16th international conference on Intelligent user interfaces*, pages 445–446. ACM, 2011.

[35] Hyunchul Lim, YoonKyong Cho, Wonjong Rhee, and Bongwon Suh. Vi-bros: Tactile feedback for indoor navigation with a smartphone and a smartwatch. In *Proceedings of the 33rd Annual ACM Conference Extended Abstracts on Human Factors in Computing Systems*, pages 2115–2120. ACM, 2015.

[36] S P. Mariotti. *Global data on visual impairments*. World Health Organization, 2010.

[37] Andréa Britto Mattos, Carlos Cardonha, Diego Gallo, Priscilla Avegliano, Ricardo Herrmann, and Sergio Borger. Marker-based image recognition of dynamic content for the visually impaired. In *Proceedings of the 11th Web for All Conference*, page 34. ACM, 2014.

[38] Troy L McDaniel, Sreekar Krishna, Dirk Colbry, and Sethuraman Panchanathan. Using tactile rhythm to convey interpersonal distances to individuals who are blind. In *CHI'09 Extended Abstracts on Human Factors in Computing Systems*, pages 4669–4674. ACM, 2009.

[39] Hirotaka Osawa. Emotional cyborg: Complementing emotional labor with human-agent interaction technology. In *Proceedings of the second international conference on Human-agent interaction*, pages 51–57. ACM, 2014.

[40] Jerome Pasquero, Scott J. Stobbe, and Noel Stonehouse. A haptic wristwatch

for eyes-free interactions. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, CHI '11, pages 3257–3266, New York, NY, USA, 2011. ACM.

[41] Huimin Qian, Ravi Kuber, Andrew Sears, and Elizabeth Stanwyck. Determining the efficacy of multi-parameter tactons in the presence of real-world and simulated audio distractors. *Interacting with Computers*, page iwt054, 2013.

[42] Shi Qiu, Jun Hu, and Matthias Rauterberg. Nonverbal signals for face-to-face communication between the blind and the sighted. 2015.

[43] Jussi Rantala, Jari Kangas, Deepak Akkil, Poika Isokoski, and Roope Raisamo. Glasses with haptic feedback of gaze gestures. In *Proceedings of the extended abstracts of the 32nd annual ACM conference on Human factors in computing systems*, pages 1597–1602. ACM, 2014.

[44] Reza Rawassizadeh, Blaine A Price, and Marian Petre. Wearables: has the age of smartwatches finally arrived? *Communications of the ACM*, 58(1):45–47, 2014.

[45] Shawn E Scherer and Myra R Schiff. Perceived intimacy, physical distance and eye contact. *Perceptual and motor skills*, 1973.

[46] G Simmel. Sociology of the senses: Visual interaction. *Introduction to the Science of Sociology*, (3):356–361, 1969.

[47] M Iftekhar Tanveer, ASM Anam, Mohammed Yeasin, and Majid Khan. Do you see what i see?: designing a sensory substitution device to access nonverbal modes of communication. In *Proceedings of the 15th International ACM SIGACCESS Conference on Computers and Accessibility*, page 10. ACM, 2013.

[48] Shafiq ur Réhman and Li Liu. Vibrotactile rendering of human emotions on the manifold of facial expressions. *JOURNAL OF MULTIMEDIA*, 3(3), 2008.

[49] Gareth R. White, Geraldine Fitzpatrick, and Graham McAllister. Toward accessible 3d virtual environments for the blind and visually impaired. In *Proceedings of the 3rd International Conference on Digital Interactive Media in Entertainment and Arts*, DIMEA '08, pages 134–141, New York, NY, USA, 2008. ACM.

[50] Koji Yatani, Nikola Banovic, and Khai Truong. Spacesense: representing geographical information to visually impaired people using spatial tactile feed-

back. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, pages 415–424. ACM, 2012.

[51] Hanlu Ye, Meethu Malu, Uran Oh, and Leah Findlater. Current and future mobile and wearable device use by people with visual impairments. In *Proceedings of the 32Nd Annual ACM Conference on Human Factors in Computing Systems*, CHI '14, pages 3123–3132, New York, NY, USA, 2014. ACM.

[52] Robert B Zajonc. Feeling and thinking: Preferences need no inferences. *American psychologist*, 35(2):151, 1980.

[53] Paul A Zandbergen and Sean J Barbeau. Positional accuracy of assisted gps data from high-sensitivity gps-enabled mobile phones. *Journal of Navigation*, 64(03):381–399, 2011.