A Wireless Navigation System For the Visually Impaired

Capstone Research Project
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Abstract- Although there is an immense population of the visually impaired around the globe, technology has not advanced enough to cater to their needs. This implies that the state of art is neglecting an important section of our population. Our research aims to create a prototype which will encompass technologies such as SONAR, Remote Sensing, GPS, and Cloud Communication. This model will integrate sensing and wireless components to provide a haptic feedback given to the user to ensure a safe and accurate navigation mechanism. Some of the sub-problems that we faced during the course of our research were deciding on cost-effective and interoperable solutions, integrating the obstacle detection mechanism with location detection and implementing open source code and efficient coding techniques. An economically viable product which used open source was the key element to developing our prototype. Our system is a replacement to the conventional navigation tools like the cane and guide dog. Being independent and healthy are the primary needs for the disabled and this device can help them achieve that goal.

Keywords - SONAR, GPS, navigation, haptic feedback, light sensing, pulse sensing, Cloud.

I. INTRODUCTION

The blind often try to use routes that are known and have the least obstructions in their daily commute. A visually impaired person usually relies on feeling floor surfaces with their feet or using footstep echo’s [1] to detect obstructions which is not a fool-proof mechanism. By integrating augmented reality with obstacle detection the visually-impaired person can be given location and orientation information instantly [2]. This research aims at improving the conventional navigation system that is used.

i. RESEARCH QUESTION AND SUB-PROBLEMS

Our research question is, “Is the wireless navigation system a practical replacement for the cane stick or the guide dog used by the visually impaired to navigate?”

Our first research sub-problem began by surveying the visually impaired community for feedback on our technology. This was a critical part of our research as it had to cater to the needs of the blind. The feedback we got from them has been incorporated into our prototype.

Our second research sub-problem focused on deciding cost-effective and interoperable components. As a significant portion of the visually impaired population live in low-income settings an economically viable product is essential. It was imperative to achieve interoperability between the components in the real-time.

As a part of our third sub-research problem we focused on integrating obstacle detection mechanism with location detection. As the SONAR Obstacle Detection mechanism has to communicate with the Global Positioning System in real time, this communication cannot falter as it is putting a life at stake. This was the most critical part of our project.

Our fourth research sub-problem focused on deciding upon suitable open source code and using efficient coding techniques. Some of the open source code available from the various vendors has been shortlisted by us to be implemented in our capstone project. Open source codes in languages such as C, PHP and MySQL should be used. However, we used Arduino Boards as controllers for our prototype and this board can be programmed with C.

Our fifth research sub-problem dealt with the integration of sensing and wireless technologies. As we incorporated additional technologies such as pulse sensing and light sensing, it was important for all the modules to be working in synchronization at the same time. If the pulse of the wearer falters at any time (i.e. it exceeds or falls below thresholds) it is important that an emergency signal is sent to the nearest
care ward or 911 services. We planned to integrate an application through which the user (who can be a relative assigned by the owner of the navigation system) could monitor the location and health parameters of the owner (the person who owns/wears the navigation system). Thus, all the above research sub-problems needed to be analyzed critically to provide the best solution to our capstone project.

ii. PROBLEM SETTING

According to the World Health Organization (WHO), 285 million people are estimated to be visually impaired: 39 million are blind and 246 million have low vision [4]. Moreover, ninety percent of this population live in a low income setting [4]. Visually impaired people are dependent on a cane stick, specially trained guide dogs or, in certain circumstances, a good Samaritan to help them navigate. There are a variety of obstacle avoidance mechanisms that can be used such as electromagnetic tracking devices to detect obstacles [1], RF (Radio Frequency) localization [2] or ultrasonic SONAR (SOurd Navigation And Ranging) sensors [1]. None of these techniques, if used independently can offer a concrete solution to aid the visually impaired. Even though there are numerous prototypes and product designs available, none of them are economically feasible for a majority of the blind population.

Through our project, we aim to develop a prototype which will incorporate technologies such as GPS, SONAR and Wi-Fi that can communicate with each other to increase the accuracy of the navigation system. Functionalities such as location detection with accurate GPS co-ordinates and navigation for the user with real-time obstacle detection are prime objectives of our prototype. This project is also designed to measure the feasibility and reliability for creating an augmented reality based navigation system. Finally, after lab testing, our real-world tests aimed to measure the feasibility of our prototype to replace the cane stick or the guide dog.

II. LITERATURE REVIEW

The visually impaired have a lot of challenges they face in their day to day lives. Tasks that seem to be so meagre to able bodied people such as a walk in the park or social networking with friends may not be that simple. Most of the visually impaired individuals do not have a very high income thereby accessibility to resources are again limited. Research on the blind shows that the visually impaired who are secure and capable of movement are better adjusted psychologically and have an easier time in gaining employment [8]. Thus, the need for an easily accessible navigation tool comes into the picture. Some other researches include the ‘Multimodal Electronic Travel Aid’ device which uses a laser pointer to gauge the angular depth and position of the object [9]. This mechanism is heavy on power consumption due to the use of a laser, hence the battery life of the device suffers. Some research focuses on vibrations as an output mechanism which is commonly known as the vibrotactile feedback [10]. There also was research conducted for astronauts to not feel spatially disoriented when there is lack of gravity [10]. This was used as a prototype to build similar technologies for the visually impaired.

In the paper presented by a team working on “Development of the navigation system for the visually impaired by using a white cane,” presented at an IEEE conference, the authors stated two important ideas [13]. Firstly, the visually impaired use the White Cane to detect objects and navigate in areas familiar to them but the cane only serves as an object detection mechanism in unfamiliar areas. Secondly, the inability of the cane to help the visually impaired in an unknown location could be solved using color coded lines for navigation. The proposed system could enable the cane to follow the lines with the help of color coding and vibration. This further helped solidify our plan to use tactile feedback in our system. The use of color coded line navigation was a concept implemented in Japan, but it would not be a viable option for us to set up sensor based lines in many indoor environments because of logistical constraints. It is hypothesized that, people with a visual impairment respond better to tactile feedback to assist them in navigating and understanding the surrounding environment.

The chapter on “GPS-based navigation system for the visually impaired” explains the growing need for portable navigation systems [14] and also states the importance of wearable technology for the visually impaired. The article helped us realize the need for a prototype which would need to have a low form-factor and is capable of being used as a wearable technology for the user. With the help of this article, we also understood the need to work on a navigation system which would focus on object detection as well as navigation. Their experiments conducted on nine subjects stated that spatialized speech and changes in volume as well as tone helped the visually impaired user to react faster. Our system needed to incorporate the feedback for object detection with changes in volume or tone to enhance the user as well as the prototype’s efficiency. After further discussions and analysis, we decided to incorporate the change in frequency of sound and vibrational feedback with addition of multi-directional feedback. We hypothesized that this method would further improve the feedback as well as understanding the environment for the user when compared to the system discussed in the article.

Also, we wanted to add monitoring functionality with our wearable navigation system. The authors of the paper “Combining wearable sensors for location-free monitoring of gait in older people” helped us broaden our understanding on the need for additional monitoring applications [15]. To further enhance the scope and features of our system’s prototype, we decided to develop an application for our navigation system which would enable the user to assign trusted relatives to monitor the location of the user as well
enable the user to notify the relatives or 911 in case of an emergency. We also planned on adding a Pulse-sensor in our prototype to enable auto-emergency alerts for the owners to the user.

III. RESEARCH METHODOLOGY

Surveys and Questionnaire:

Our project began with the creation of a survey questionnaire which would help us gauge some information on our product. As our product is very specific to the community of the visually impaired it was essential for us to understand and cater to their needs. We prepared a questionnaire of 15 questions which was distributed to schools in Denver through November, 2015. As we knew, our project was extensive and the time available was limited, the initial surveys were conducted within University of Colorado, Boulder. We worked with the CU Disability services and they were very helpful in gathering resources. We also managed to get all our questions printed in Braille as shown in Fig. 1.

![Questionnaire translation using Braille](image)

**Fig. 1. Questionnaire translation using Braille**

Interviews:

We conducted interviews with various industry experts who are pioneers in their field. Our first interview was with CU Disability Services. We contacted S. Kelmer, who is the Alternate Format Access Coordinator. She has dealt with a lot of visually impaired students. She explained an incident where one of the students had suffered from anxiety issues. The student used to forget where she kept her belongings and then get very anxious as she thought she had lost it. Susan mentioned that this tool can help such individuals and make them feel safe and secure.

Our next interview was scheduled at the Colorado School for the Deaf and Blind located in Colorado Springs on December 5th, 2014. At the school, we worked with D. Covington (school/community liaison) and faculty, M. Rahn, L. D. Vandam and G. Gates. The integration of the SONAR sensor with the GPS system is not something they have seen in the past. We were given a demonstration of the tools that were available in the market and we also discussed the pros and cons of these tools in depth.

We observed a group of 6-10 year old visually impaired students for 1.5 hours. This observation helped us analyze the everyday difficulties that the blind face. One task assigned to them was to fill a cup with water; the students were each given a device that would vibrate once the cup was filled with the liquid to a certain level. This task helped us determine that a tactile feedback would be the best output for our tool. We were then taken to the mobility services located at the school. Maps, study material and a lot of resources have been translated to braille to provide equal access to all with disabilities. The school provides training to military personnel. Some of the training includes being blind folded and completing a set of task which has strenuous physical activity involved. A major difficulty faced by the military trainees and the visually impaired are the low overhead branches of trees. To date, technology has not provided a solution to this. This resulted in a solution to incorporate SONAR sensors in cap/sunglasses to alert the wearer of any low hanging branches.

As we are making a tool for the visually impaired we thought it was imperative to get a survey/interview at a retail store. Beyond Sight is the largest and most popular retail store in Denver and they claim to be Colorado’s exclusive dealer for enhanced vision [18]. The store owner was visually impaired himself and was well-versed with the concerns of the community. He told us that the products available in the market today are very limited. The best product they have today is called the Trekker Breeze which is a handheld talking GPS. This product is currently priced at $699.34 [18]. This product is expensive and has very limited capabilities.

The store owner has a guide dog and he enunciated some of the difficulties he faced with the dog. Firstly, the dog has to be trained along with the owner to cater to the owner’s requirements. For this training, he had to go to Portland, Oregon for a week. As he is visually impaired, this was a difficult task to complete. Secondly, he narrated various incidents where the dog got confused while trying to cross the street which has resulted in a lot of accidents. Thirdly, the expense of maintaining a dog can be a hardship for people living in low income settings. Thus, we felt that our system can be an inexpensive, one time and reliable solution to the community of the visually impaired.

Our team also conducted various phone based interviews. We contacted American Council of the Blind of Colorado, where D. Calkins who is the administrative and volunteering program assistant assisted us with our surveys.
Darlene is a high partial visually impaired person with glaucoma. She has twin sister who is completely blind. She had a really good grasp on technology and she was almost at par with our device. As children are most open to new technology we approached Anchor Center for Blind Children for a phone based interview. We worked with A. Peralta, program director of this prestigious institute who was very enthusiastic of all the features our prototype could provide.

Apart from this, we have collected surveys from various anonymous sources. These sources are spread across the globe from countries like India, Saudi Arabia and the United States. Some statistical data that we acquired are as follows:

1. 47% of people prefer using the traditional method of the cane stick. The rest of the community is open to the idea of a wireless navigation tool.
2. 89% of the community use cane sticks as the most common mode of navigation. The rest of the 11% use guide dogs.
3. 58% of the community spend anywhere between $700-3000 on various tools for navigation. 40% spend $200-699. The rest 2% cannot afford to spend more than $200.
4. 93% preferred acquiring obstacle detection using haptic feedback. 7% preferred getting both haptic and auditory feedback.
5. 97% of the community prefers using the tool as a wearable. They would like it to be a pocket/ handheld device which can be concealed easily. The rest of the 3% were comfortable with any device until their purpose is solved.

**System Components:**

1] Micro-controller - Our team recognized early on in the research process that we would need a reliable microcontroller. This is primarily the reason for choosing Arduino Yun. Arduino Yun is the only microcontroller based on ATmega32u4 and the Atheros AR9331 due to which it has both Ethernet and Wi-Fi support and hence proved to be the most appropriate choice for our research. This element is the “Brain of the prototype” and processes all the input and output.

As our prototype has been divided into three models based on the business perspective, we have used two different microcontrollers. For the Gold and Silver models, we have used Arduino Yun as it has Wi-Fi capabilities. In case of our Bronze product, we have used Arduino UNO which has no Wi-Fi capabilities but satiates all the other processor needs.

2] SONAR Sensor - SONAR is the technology we adopted to conduct object detection. For this we used four Parallax PING Ultrasonic Sensors [19]. Three sensors are mounted on the trousers. The fourth sensor is mounted on a hat. As our surveys indicated the need for sensing low-lying overhead branches, our ultrasound sensor on the cap can help detect the same.

There was an option to select infrared technology as an obstacle detection mechanism. The biggest limitation in this method is that it will not work in all types of lighting condition. The lighting condition has to be good for the objects to get detected. Secondly, the accuracy of detecting an object is higher in the case of an ultrasonic sensor as compared to an infrared sensor. Thus, we opted for ultrasonic sensors.

3] GPS Module - For this element, we are using a Skylab GPS Module MT3329 SKM53. This has “an embedded GPS antenna and is based on MediaTek3329 single-chip architecture” [17]. The GPS is used to give positional information such as latitude and longitude. For this research, we have used the open source Google Maps API to resolve the latitude and longitudinal information. The latitude and longitude information is converted to street addresses for ease of detection by the user.

4] Vibrator – Four vibrational motors have been used with each of the four sensors. As our survey indicated a preference of haptic feedback, it has been incorporated in the system.

5] Buzzer - To cater to the needs of an auditory feedback, a buzzer has been used to warn the user of any obstacles. As the distance of the object detected decreases, the sound intensity increases.

6] Pulse Sensor - To establish this feature in our prototype, we have used an open source sensor called Pulse Sensor. Its functionality is based on the photodiode technology. The output is measured as beats per minute (bpm). We have created a default threshold window of 80-130 bpm. This threshold has been calculated using the universal heart rate equation:

$$HR_{max} = 206.9 - (0.67 \times \text{age})$$

The owner has an option of customizing the thresholds through the web-application. If the pulse rate is not in the range of the safe window, an alert will be sent to the emergency care unit of the owner’s choice. This element can ensure the health and well-being of the user at all times.

7] Light Sensor – A photo-resistor Light Dependent Resistor (LDR) light sensing module which is sensitive to ambient light intensity has been used. This module has configurable thresholds where if the light intensity drops down it reflects a low output and vice-versa. This element will primarily be used by users with low night vision. The Light Emitting Diodes

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**Components:**

- **Light Sensor** - A photo-resistor Light Dependent Resistor (LDR) light sensing module which is sensitive to ambient light intensity has been used. This module has configurable thresholds where if the light intensity drops down it reflects a low output and vice-versa. This element will primarily be used by users with low night vision. The Light Emitting Diodes.
(LEDs) can enhance the user’s vision. This feature can also help alert cars and other pedestrians of the device’s wearer.

8] Emergency Button – This is also called the Panic Button. If the owner pushes this button, an alert is send to a pre-assigned user of the owner’s choice. This alert is sent via an email and phone call. The user has an option to assign 911 as one of its emergency contacts.

9] Power Source – Currently, a 5V lithium ion battery has been used as a power source.

10] Web Application – Once the owner has received the device, he has to login to the webpage and sign-up using his name, email-id, phone number and MAC address. The owner can then add up to 5 users depending on the model he/she has selected. The owner adds these users by adding their name, phone number and email-id. The owner is prompted two security questions:

- Can the user access the location data?
- Can the user monitor his pulse rate?

The application has options to set thresholds for the heart rate and also modify the user who can view the location. Once the emergency/panic button is pushed, the owner has to specify the user who is alerted to this information (location and pulse).

Test Bed:

Our prototype (as shown in Fig. 3) was initially tested indoor in the DLC (Discovery Learning Centre, CU Boulder) lobby. Originally, the prototype was developed on a waist belt. Our initial thought process did not account for low-lying objects such as rocks, pebbles or even a flight of stairs. The waist belt was really useful in testing and detecting trees, tables, chairs and even another human. We had three SONAR sensors mounted on the belt facing the front, left and right. These sonar sensors where attached to a haptic device. Initially during our testing we preset the distance on the SONAR sensors to 50cm.

We decided to have only one vibrating motor with three levels of vibrational intensity. This would help our device consume less power. Our team decided to have Faisal Khan (one of our members) as the pilot tester. As a tester he was unable to differentiate between the levels very precisely. We realized that this mechanism would require a lot of training. This could demean the value of our prototype. A major concern we had at this juncture was that if the user gets confused of the direction from where the object is approaching, it could be catastrophic as we are risking a human life. It was a trade-off between functional efficiency and battery life.

We opted for using three separate vibrators, each placed adjacent to the sonar sensor. This would enable the user to determine the direction of the object with ease. As the object is less than 10 cm, the auditory alarm will start beeping.

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Fig. 2. Web-Application flow-chart

Fig. 3. Block Diagram of the Prototype

Integrating the GPS receiver into our prototype was a real hurdle for the team. A major concern faced was that we could not receive the GPS co-ordinates such as latitude and longitude on CU’s VPN. Thereby, we had to move outdoor to an open Wi-Fi network for conducting our testing on the GPS. In our initial tests, we had to maintain the required temperature to connect our GPS with Arduino as even a slight deviation from the required temperature could have burnt our tool. We used the GPS proto-shield as a platform to secure the contact of receiver with the micro-controller. We still face the concern of some time lag before we can start receiving co-ordinates in our web-application. However, that would be the future scope of this project to make it real time.

Further on, we had to integrate the Pulse sensor with the Arduino to track the beats per second (bps) of the visually impaired. We chose an environment with dry conditions and minimum humidity. Moisture or any water content in the surroundings could have damaged our Pulse sensor. In addition, we minimized the contact of the pulse sensor with external atmosphere by insulating it with black tape.

Finally, we chose to minimize the wiring and soldered all the equipment firmly. Our prototype was sewed to a pair of trousers. The trouser had 3 SONAR sensors each associated with a vibrator, emergency push button, GPS receiver, Pulse sensor and two Arduinos. We also used a cap with an additional SONAR to detect the overhead branches. This cap can be replaced or used with the sun glasses for visually impaired. Our final testing was conducted outdoor on the CU campus with the pant.

IV. RESEARCH RESULTS AND DISCUSSION

We had our prototype functionalities in place with the cap and trouser. The prototype functionality is divided into two parts; the first part mainly concerns with the obstacle detection mechanism that can function off the prototype itself. The second part focuses on the tracking function and requires communication with the web application, which will process the data.

The first part:

We have three SONAR sensors attached to the right, center, and left of the trouser so it can scan a 180 degree perimeter, thereby covering any obstacle in front of the person. The SONAR sensors are programmed to detect obstacles that are 50 cm away from the person. The fourth SONAR sensor is attached to the cap to detect any over-head obstacles. Once any of the sensors detect an obstacle, the vibrator attached to the sensor will vibrate and the buzzer will make a tone to warn the person that he is approaching an obstacle in that direction. We have the light sensor, which senses the intensity around the person. In case of low light condition, two red LEDs will be turned on to provide additional lighting to the visually impaired person as well as help alerting the cars and pedestrians. These LEDs can be replaced with an LED strip to provide more brightness and visibility.

The second part:

This part collects real-time information and sends it to the web application (Fig. 4) by connecting to the Internet gateway though the Wi-Fi module that is available in the Arduino Yun. The prototype will collect the person’s current location, pulse per minute and the status of the emergency button and send it to the web application every 10 seconds (approximately) and perform the defined action if needed. Our web application is implemented in highly robust platform that ensures a reliable operation as well as securing the owner’s information.

Initially, the owner has to register the prototype in the web application as shown in Fig. 5 by providing basic information in addition to the prototype MAC address that is used as the device identity.
After registering the device, it will start communicating with the application and send the owner’s location, heart rate and emergency button status. When the owner logs in for the first time using the owners’ login section, he will get the main page (Fig. 6) displaying the application features and alerting the owner that his/her profile is not programmed and there are no users to monitor him/her.

Then the owner has to edit his/her profile by entering the heart rate thresholds and selecting the user(s) to be notified in case an event is triggered. Then, the owner as well as the user can view the real-time location (Fig. 9) and heart rate logging.
Fig. 10. Event logs

V. BUSINESS PERSPECTIVE

Our navigation system prototype required a total investment of $580 to build. This cost includes even the components that failed during testing and programming such as the GPS module, LEDs, Power cables and other miscellaneous components. We have not included the cost of equipment purchased by our department with the help of our Advisor, Joe Mcmanus. The total of cost of this equipment is approximately $650. These include soldering iron, multimeter, flux, wires and power supply.

Thinking from a production perspective, we can have different variants of our product based on the requirements and budget of the user. The business model is based on an initial low cost of ownership and recurring monthly payments to provide an incentive for the buyer and the manufacturer. These are:

**BRONZE**

PLAN: Initial payment of $49.99
+ $3.99 every month for 24 months

Features:
- Tri-directional Sonar sensing with triple-vibrotactile feedback.
- Sonar capable cap/sunglasses with branch-sensing capability.
- Training and user customizations of the system sensors such as volume, vibration and detection distance based on the user’s preferences.

**SILVER**

PLAN: Initial payment of $69.99
+ $6.99 every month for 24 months

Features:
- Features in BRONZE +
- GPS - capability for enhanced location tracking and monitoring for one (1) additional user with the help of our web-application.
- EMERGENCY BUTTON enables Emergency notifications for sending text message with GPS coordinates to two (2) pre-assigned telephone number (number can be swapped for 911 services)
- Only one time cost of $10 for additional emergency numbers
- Free software upgrade in case of new software release

**GOLD**

PLAN: Initial payment of $99.99
+ $9.99 every month for 24 months

Features:
- Features in Silver +
- GPS monitoring and tracking with our web-application for up to two (2) additional users.
- Emergency notifications for up to five (5) numbers including 911 service.
- Luminance sensor to automatically activate LED power saving lights in case ambient light conditions reduce visibility for others.
- Pulse sensor with threshold levels set by medically accepted standards to send warning messages (in case of pulse rates reading above or below the threshold levels) to relatives assigned by the user.

Below is a figure to summarize the business aspect:

Fig. 11. Product variant and feature table

VI. CONCLUSION AND FUTURE RESEARCH

With the advancement in technology, the community of visually impaired have been neglected. Although there are
some products available to assist them with navigation, they lack efficiency in terms of cost and performance. There is a lot of popularity with wearable technology, but there are no products available for indoor as well as outdoor navigation for the blind.

Our research aims to enable the visually impaired community to navigate as well detect objects while understanding the surrounding environment with the help of vibrotactile feedback. The primary goal of our research is to develop a reliable alternative to the cane stick or the guide dog used by the visually impaired to navigate while adding monitoring as well security features to enhance the state-of-the-art. We have managed to provide object detection with the help of SONAR in all three directions. Our open source web-based application synchronized with our GPS module on the navigation system will enable the owner’s relatives to keep track of the owner’s location. The emergency button, Pulse sensor and Light sensor will further improve the safety aspect of our system. Most importantly, we are trying to develop a product which can be commercially produced at the lowest cost with highest number of features when compared to the competition.

Our research can be a good platform for someone who would like to start production for these navigation systems. We also have some ideas for future research and enhancements on our system. First, there are number of technologies which are in their nascent stage but, if proven successful, wearable technology can be used to stitch all our circuits into the user’s clothes [16]. During our survey, we came across a common request that the users did not want to stand out in a crowd. With the wearable technology, the product could have a designer appeal, something which the users highly desire [16]. Second, there should be a study done to improve the accuracy of indoor GPS. Third, the system can be further enhanced with the use of piezoelectric-sensors which can detect the capacitance and warn the user in case of changing terrain conditions such as black-ice, water or oil-spill. Fourth, the over-head branch detection sensors can be incorporated in sunglasses so as to provide an alternative to the cap. Fifth, the SONAR sensors should be improved to warn the user with speech feedback in case of an approaching target such as a cyclist. In our current version of the system, we do not consider the targets to be approaching faster than walking speed. Also, there are cases when the cyclist could be unaware of the user being blind and expecting to yield way to the cyclist. The system should be capable of warning the user as well as activate some emergency notifications to the cyclist.

To sum up, the system provides numerous additional features which the competing systems do not provide and can be an alternative or a very good enhancement to the guide dog or the cane stick if the user does not wish to give up the cane or the dog.

VI. REFERENCES


