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Developing a LiDAR Topographic Navigation System: A Novel Approach to Aid the Visually Impaired

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Abstract

The WHO reports 2.2 billion people internationally have a form of visual impairment, with Perkins School of Blind adding that 4 to 8 percent (8.8 - 17.6 million people) solely rely on a white cane for navigation. In an interview by Stephen Yin for NPR, visually impaired interviewees claimed that a white cane was ineffective as it failed to detect moving obstacles (ex. bikes), aerial obstacles (ex. falling objects), and it became physically demanding after a prolonged period. This problem can be solved with a headset that integrates LiDAR technology and haptic feedback to provide a real-time assessment of their environment. Theoretically, the device will determine how far an object is from the user and place it into one of three conditionals based on distance (0-290mm, 310-500mm, 510-1200mm). As the user gets closer to the object, the haptic will vibrate more frequently. The device has 11 LIDAR sensors, beetle processors, and ERM motors so that when the LiDAR detects an object, the device will send a haptic signal in that area. It not only identifies the existence of an object but it tells the user its relative position with a latency period of approximately 2 milliseconds. When testing the device, a simulated walking environment was made. Ten obstacles were included: five below the waist (72”, 28”, 35” and 8.5” tall sticks) and five above the waist (paper suspended 6”, 10”, 48” and 28” from the ceiling). The white cane detected 4.1 obstacles, whereas the device detected 7.3 on average. The LiDAR navigation system is 178% more effective at detecting objects comparatively. Visually impaired individuals no longer must rely on the white cane; rather, using this device, they can detect small, moving, and aerial objects at a much faster, and more accurate speed.

Keywords: Haptic/Vibrotactile technology, Research and Development, Visual impairment, Biomedical/LiDAR assistance

Introduction

Globally, billions of people have a visual impairment (WHO, 2022, p.1). Visual impairment encompasses both complete and incomplete blindness. The umbrella term includes many disorders, commonly: Strabismus, Glaucoma, Cataracts, and Diabetic Retinopathy. It is challenging for people with disorders like these to navigate daily life. Tasks such as maneuvering a city are arduous without complete visual sensations. Research led by occupational therapist Diana M. Brouwer found that people with visual impairment are unfailingly met with limited mobility because of their condition. The study further expands that visual disorders negatively affect the mental well-being of patients (Brouwer, 2005, p.4). The number of people with visual impairment is expected to increase throughout 2050, so researchers are increasingly presenting assistive technologies as viable solutions to problems faced by the visually impaired. (Varma, 2016, p. 7)

Many visual disabilities are degenerative, meaning the patient's condition worsens irreversibly over time. For instance, Age-Related Macular Degeneration (AMD), a common degenerative disorder, causes severe blurriness for those affected and is the leading cause of vision loss in older patients. (NIH, 2021, p. 1). Acclimating to a new environment as a condition deteriorates is demanding for the patient. A degenerative disorder forces those affected to adapt at an accelerated speed. Furthermore, to tackle difficulties associated with visual impairment, increased demand for assistive and learning technology is evident. (Varma, 2016, fig.2) The development of assistive navigational devices for those with degenerative visual disorders is needed now more than ever.

This study aimed to develop and investigate the efficacy of a LiDAR navigational device in assisting the visually impaired.

In a study published by the American Medical Association, evidence suggested that hearing loss prevalence increased by 18% and 13% for those with visual impairments (Chia, 2006, p.3). Given that visual impairments go hand in hand with hearing loss, this study's focus was to develop a device that provides feedback through touch using haptics. By replacing visual cues with vibrotactile responses over auditory signals, the device is more accessible.

Amid the pandemic, people with disabilities have struggled immensely. Transitioning from touch and tactile communication, to complete isolation with unique behavioral changes has been particularly difficult, especially for people with visual impairments.

To solve this problem, R&D departments have published extensive assistive designs. Nevertheless, many proposed technologies eventually became more of a burden for visually impaired users. Navigational solutions released onto the market, such as the "mini-guide," "smart shoes," and guide dogs, have failed to succeed partly because of their expensive nature: $600, $380, and $20,000, respectively. However, the fundamental problem with the devices above is that they only detect obstacles below hip height, so sensors were placed in a region susceptible to faulty. In these solutions, sensors were in mobile areas such as the user's finger or torso. Consequently, they were often falsely triggered by the movement of the user's body.

To avoid such errors, the sensors used in this study were on the user's head, a stable, non-restrictive part of the body. This study intends not only to build upon prior research but also to present a novel, inexpensive, realistic prototype for use in everyday settings. The overall focus of this research was to develop a prototype that helps the visually impaired through haptic feedback and reliable notifications.

Research Methodology

The focus of the study was to create a highly specialized, effective, and convenient device. To achieve such, precise Light Detection and Ranging Sensors (LiDAR) were used in conjunction with Eccentric Rotating Mass vibration motors (ERM) to collect and then relay navigational information to the user.

To test the efficacy of the proposed device, the researcher conducted preliminary testing on themself. Initially, testing was planned to extend beyond the research team; however, the COVID-19 pandemic limited the organization of additional experiments with human subjects (although future research plans are presented further in the paper).

The researcher made various prototype iterations in the maturation of the device. The device advanced from a simple ultrasonic system to a complex network with LiDAR and haptic integration.

Prototypes that were paramount in the production of the final device are listed below:

i. AJ-SR04M module Ultrasonic System

The AJ-SR04M rudimentary prototype relied on an ultrasonic sensor to calculate obstacles in the user's path. The ultrasonic sensor transmits an audio signal at a frequency too high for humans to hear, then calculates the distance from an obstacle using the signal's time of flight.

This ultrasonic method was versatile and promising. The AJ-SR04M module had low voltage consumption, a 4.5-meter range, and a convenient beam angle of 45 degrees. This prototype used 6 AJ-SR04M elements, all operated by a single Arduino Mega 2560 Rev3 microcontroller board. Each ultrasonic driver board communicated with the Mega 2560 microcontroller using an I2C bus.

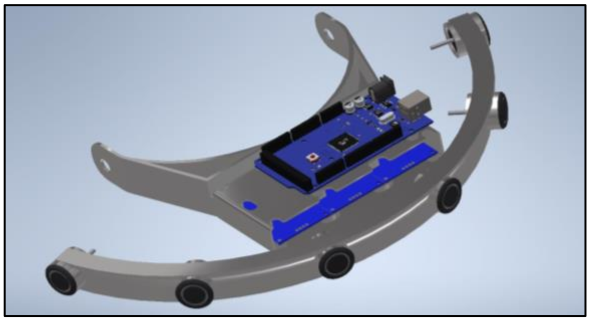

Figure 1

As the ultrasonic module detected an obstacle ahead, the microcontroller received the signal and triggered ERM motors along the user's head. When the user got closer to an object, the motors would vibrate more frequently to indicate dangerous proximity. Hypothetically, this helps a user comprehend the presence of obstacles in their path, as the device sends a light vibrotactile response using ERM motors along their head.

The device was designed on Autodesk AutoCAD Inventor 2018 and was printed on a FormLabs Stereolithographic (SLA) 3D printer using photopolymer blue resin, seen in *Figure 1*.

This system worked in theory, but the data had many inconsistencies in practice. A short 65-millisecond delay was apparent and became an obstacle in testing. Although the device was accurately wired, and the software was uploaded correctly to the microcontroller, there was still a delay. Thus, the delay in response was unusual. Hypothesized that the time delay was because the microcontroller had to multiplex information from 6 different sensor assemblies. The delay may have also been attributable to the spectral width of the sensors. The spectral width was too broad, so sensors reported incorrect information to one another.

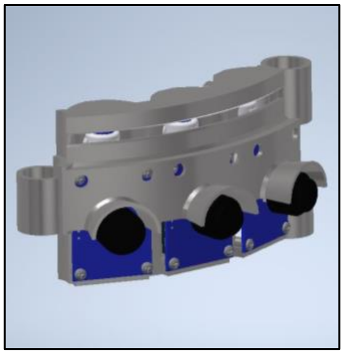

Figure 2

Furthermore, the device lacked the precision and resolution required to map an environment accurately. Because the spectral width of the sensors was so vast, multiple sensors were triggered when a user encountered a single obstacle, so it was impossible to navigate without knowing exactly where the object was.

To control the wide beam of the ultrasonic sensors, the design was modified on AutoCAD so that a horn directed ultrasonic signals. *Figure 2* displays the modification in design with horns centered around each sensor. Despite this change, the device still needed to be more accurate. During this process, the device became very big and appeared too bulky.

Ultimately, this prototype became too impractical because of its unrealistic size. Delays and lack of resolution further ceased the development of this device.

ii. TOF-10120 LiDAR System

Shifting away from an Ultrasonic System, the following fundamental prototype used LiDAR sensors to detect obstacles around the user. The device used a small LiDAR TOF-10120 sensor with a decremented range of 4 meters.

LiDAR systems like this emit infrared light and use time-of-flight (TOF) to calculate the distance between the user and an object (Wasser, 2022, p.2).

In contract to the previous iteration, the TOF-10120 LiDAR system had many microprocessors. Rather than having a single processor multiplex information from many different sensors, this prototype assigned a different processor to each LiDAR system. The system used DFRobot Beetle boards to process and sort information.

There were 15 LiDAR sensors, 15 ERM motors, and 15 DFRobot Beetle boards, as seen in *Figure 3.* Like the previous prototype, this device relied on I2C communication between the TOF-10120 unit and each DFRobot Beetle Board.

As the LiDAR sensor picked up a signal from the environment, the processor received data regarding distance in mm. The processor sorts the data into one of three conditionals based on how close the user is to an obstacle. This organization initiates a haptic response that varies in frequency depending on how close the user is to an object.

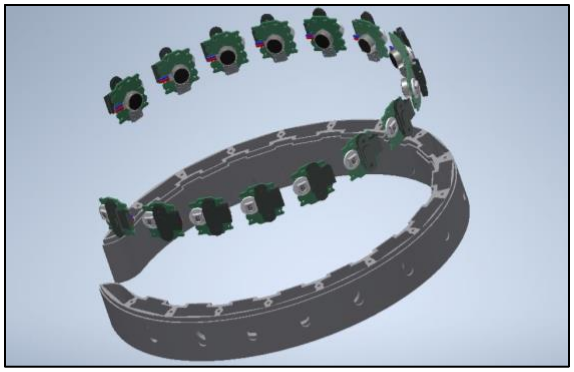

Figure 3

This iteration was critical as it birthed a concept eventually used in the final product: individual processors per sensor.

Eventually, this prototype was not developed due to a series of complications. The Integrated Development Environment (IDE) showed a 1500 millisecond delay between the time the LiDAR identified an obstacle and initiated a response. Hypothesized the TOF-10120 LiDAR had a problem with clarity. This device also had major material problems. The TOF-10120 LiDAR System was designed on Autodesk AutoCAD Inventor 2018, then printed on an SLA printer using rigid 10K photopolymer resin. The use of such a rigid material caused a premature crack in the design. 10K resin is highly reinforced with glass, resulting in a high tensile modulus (53-65 MPa), making it unsuitable for a long-lasting, convenient, wearable device.

As a result of significant delays and material problems, the development of the TOF-10120 unit was discontinued.

iii. Final VL53L0X Iteration

The final device (see *fig. 4*) uses a new LiDAR module to rectify the delay problem in the previous prototype. This device uses a VL53L0X element. This change proved valuable, as the delay problems were no longer present. However, to ensure the delay problems were corrected, the range distance had to be revaluated. The final product has a range of about 2 meters.

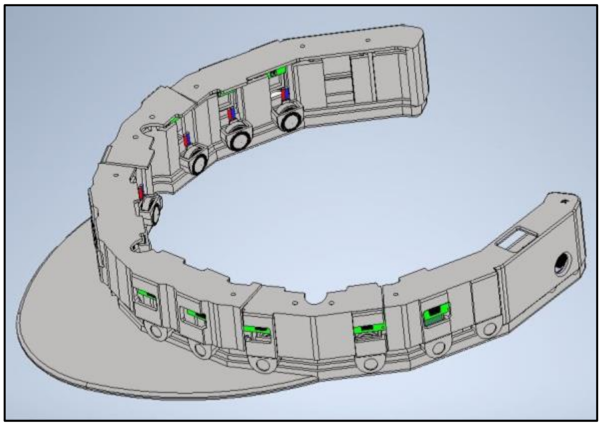

Figure 4

Flexibility points were extruded to reduce stress in the design and correct material-based problems. To do so, the number of sensors decreased from 15 to 11. Additionally, the device was printed on a Selective Laser Sintering (SLS) printer with nylon material, making it significantly more flexible. When tested among ten different trials, results showed that the device could expand an additional 5.994 centimeters.

It uses 11 DFRobot Beetle boards; each corresponds to a single LiDAR and ERM motor. The ERM motors used pulse width modulation (PWM) in the software uploaded to the Beetle boards.

Each LiDAR detector has a respective ERM motor and processor. Therefore, the user is informed not just of an object's existence but also of the object's relative region. This understanding allows feedback to be very specialized and specific.

In the final product, Neopixel lights were used for demonstration purposes. These lights help make the three conditionals more obvious for non-visually impaired researchers.

The LiDAR receives distance 'x' in mm; this value helps to sort the information into one of three conditionals. $0 \leq x < 290$ (object is very close), $310 < x < 500$ (object is moderately close), $510 < x < 1200$(object is a safe distance away). Response changes depending on how close the user is to a potential object. The three conditionals are outlined below:

$0 \leq x < 290$ (object is very close): Neopixel flashes red in intervals of 40 milliseconds, and ERM motor vibrates with 150-millisecond intervals between each vibration

$310 < x < 500$ (object is moderately close): Neopixel flashes blue in 40-millisecond intervals, and ERM motor vibrates with 250-millisecond intervals.

$510 < x < 1200$ (object is a safe distance away): Neopixel flashes green in intervals of 40 milliseconds, with no ERM vibrations.

With adequate training, the user can obtain three critical pieces of information from the device. 1) The existence of an object in the user's path. 2) The relative region of that object in their path 3) The user's proximity to that object (depending on haptic vibration frequency).

Testing Procedure

This research tested the efficiency of the developed device (mentioned prior) compared to a white cane. The independent variable in this experiment was the device tested, given that the study compared the differences between the developed prototype mentioned earlier and the commonly used white cane. The dependent variable was the number of obstacles detected by the device. Finally, the control group was a statistical analysis regarding the probability of a visually impaired user detecting an obstacle in front of them.

Trial	*LiDAR Navigation System*	*White Cane System*
1	9	4
2	10	5
3	8	3
4	5	5
5	10	2
6	10	5
7	7	5
8	9	4
9	6	5
10	10	3

Figure 5

When testing the device, a simulated walking environment was created: Ten obstacles were included: five below the waist (72", 28", 35" and 8.5" tall sticks) and five above the waist (paper suspended 6", 10", 48" and 28" from the ceiling)

The number of obstacles out of 10 detected by the respective device was recorded and later analyzed in the study.

Results

Figure 5 shows that the white cane detected 4.1 obstacles, whereas the device detected 7.3 on average. Comparatively, the LiDAR navigation system was 178 percent more effective.

The data shows that the number of obstacles in the stimulated environment detected by the widely used white cane was significantly smaller than the number of obstacles detected by the LiDAR topographic navigation system. The Lidar system detected 7 of 10 obstacles on average (avg. 7.3), whereas the widely used white cane detected approximately 4 out of 10 obstacles (avg. 4.1).

When establishing the stimulated outside environment, ten obstacles at heights ranging from 0.2 meters to 1.8 meters were arranged. Half of the obstacles were placed above the user's waist (approx. 0.78 meters), the other half below the waist of the user. The number of obstacles detected by the white cane failed to exceeded five, as it was designed to detect obstacles solely below the user's waist. In comparison, the LiDAR system provided a 180-degree perspective, detecting objects above, below, in front, and beside the user.

When the researcher graphed the data, polynomial trend lines as shown in figure 6, indicated a stark contrast in efficacy between the LiDAR and white cane systems. The white cane trend line (blue) is generally placed at a lower y-coordinate on the graph, whereas the

LiDAR trend line (red) is much higher.

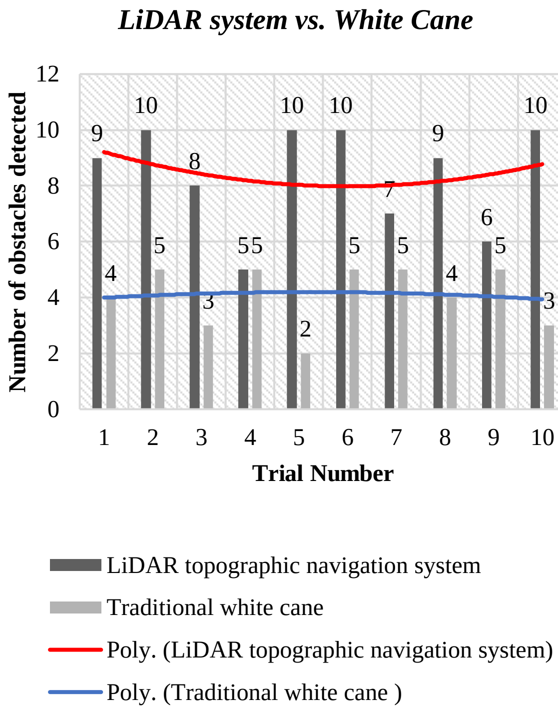

Figure 6

Discussion

Mending LiDAR and DFRobot Beetle technologies to develop such a device is unprecedented and should be explored further in later years.

This research analysis shows that LiDAR navigation systems are much more effective at detecting objects in the user's path. Using a DFRobot Beetle, ERM motors, and a LiDAR sensor, users can now detect what is in front of them and how far this object is from them. On average, the LiDAR navigation system detected 7 out of 10 obstacles presented to it (avg.7.3), which is a significant amount when compared to the meek 4 out of 10 obstacles on average detected by the white cane (avg. 4.1). The primary fault of the cane is that it does not detect obstacles above the user's hip. Comparatively, the LiDAR navigation system creates a 180 perspective that mirrors the sensations a non-visually impaired person would experience. This paper raises questions about the appeal and safety of the device to the visually impaired community.

In the future, better precision can be ensured by incorporating additional units (LiDAR, ERM, Beetle integration). Using this method, visually impaired people can identify not only the presence of an object in front of them but the size/shape of the object. The project will further improve by integrating more sensors (multi-lined/multi-layered grid) to increase precision and provide depth for LiDAR mapping. The device can use an injection molded material with a single circuit interior for cost efficiency when manufactured. Using an injection mold and flexible PCB will decrease the price by an estimated 66%, making it more accessible.

In the future, this device will be tested with visually impaired people as a part of a long-term study. In this research, the adaptability and long-term efficiency of the device will be investigated.

Developing a method where visually impaired people can navigate through their environment is especially important as they can now safely understand their surroundings in a constantly changing world. Over 2.2 billion people are affected globally by variations of visual impairment, and commercializing this device would ensure that these people receive adequate aid so they can expect and prepare for obstacles in their path.
This research is proof of incredible strides in technological assistance for the visually impaired. The study produced and tested a novel device after the cultivation of countless prototypes *(most unlisted).*

This research has potential to assist and touch the lives of countless visually impaired communities, though it still has far to go.

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The LiDAR-based navigation system for visually impaired individuals is cleverly presented. After sensing the incoming obstacle with the LiDAR，it actuates a haptic vibrator with a variable directional amplitude to remind the individual.

The idea and its implementation are excellently executed and highly admirable.