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Original Research

Development and Functional Assessment of Wearable Assistive Device with Vibration Motor for Blind and Vision Impaired Persons (BVIP)

Nur Syahira Mohd Azam[1], Nadia Shaira Shafii[2*], Ahmad Zahran Md Khudzari[2], Kahar Osman[3], Aisyah Ahmad Shafi[2], Mohamad Ikhwan Kori[2]

[1]Centre of Biomedical Engineering, University of Cyberjaya, Persiaran Cyber 11, 63000 Sepang, Selangor
[2]Department of Biomedical Engineering and Health Sciences, Faculty of Electrical Engineering, Universiti Teknologi Malaysia, 81310 UTM Johor Bahru, Johor, Malaysia
[3] Faculty of Mechanical Engineering, Universiti Teknologi Malaysia, 81310 UTM Johor Bahru, Johor, Malaysia.

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ABSTRACT

World Health Organization (WHO) stated that about 2.2 billion Blind and Vision Impaired Persons (BVIP) worldwide. There are a few types of developed and commercialised assistive devices such as walking canes and Electronic Travel Aids (ETA) to assist them. However, these devices are not hands-free, do not utilize audio output, and lack location tracking features. This study proposes a comfortable, integrated wearable system for blind and visually impaired persons (BVIP) that concurrently detects obstacles and tracks their location remotely. The established algorithm using the Arduino Uno will be integrated into the ultrasonic sensors, and PWM vibration motors before being attached to a wearable jacket. The sensor detection and battery performance tests were conducted. This is to ensure good accuracy of obstacle detection on different surfaces either outdoor or indoor environments also verifying the battery lifespan quality is adequate for daily usage by the user. In conclusion, the proposed hands-free wearable navigation assistive device showed the ability of the ultrasonic sensor in detecting obstacles in indoor and outdoor areas up to 98.66% and 98.0%, with a rechargeable battery performance of up to 7 hours and 45 minutes per cycle. This shows that the device has the potential to help users use it effectively daily.

INTRODUCTION

One billion out of 2.2 billion cases of preventable visual impairment had been reported, ranging from moderate to severe visual impairments. Several factors have been identified including uncorrected refractive errors caused by cataracts and age-related macular degeneration, glaucoma, diabetic retinopathy, and unaddressed presbyopia (Chew et al., 2018). Chew et al (2018) reported that 1.2% of disability issues are due to blindness, severe visual impairment, and slight visual visibility. 58.6 % of the cases are due to cataracts, 10.4% due to diabetic retinopathy, and glaucoma with 6.6%.

Individuals who are blind or visually impaired (BVIP) are categorized into two groups: those with distance vision impairment and those with near vision impairment. The severity of these impairments is evaluated using visual acuity tests and classified with the 6-meter Snellen chart, as illustrated in Figure 1. These test measures the ability of the eye to recognise tiniest readable letters at 6 meters. Table 1 shows the visual acuity range and its classification for impairment severity. The smallest value serves as the denominator, while the distance to the chart functions as the numerator. A visual acuity of 6/12 means that an individual at 6 meters from the chart can identify a letter that a person with normal vision can see at 12 meters. The benchmark for normal vision is 6/6 (Chew et al., 2018).

Mobility is a crucial human ability that involves understanding one's surroundings and navigating safely and effectively (Lee et al., 2014). Research indicates that a lack of sight significantly impairs mobility and orientation, which can

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* Nadia Shaira Shafii (nadiashaira@utm.my @utm.my)

Department of Biomedical Engineering and Health Sciences, Faculty of Electrical Engineering, Universiti Teknologi Malaysia, 81310 UTM Johor Bahru, Johor, Malaysia

hinder the daily lives of individuals who are blind (Dhivya et al., 2019; Dunai et al., 2014). Blindness and visual impairments may lead to difficulties in various aspects of life, education, and employment opportunities. BVIP require safe and systematic navigation to improve mobility as well as hazard avoidance such as curbs, potholes or stairs. Normally, traditional navigation tools like canes and guides animals are used for navigating (Chang et al, 2020). However, a normal cane has limitations in detecting obstacles that are up to the knee level which are achieved by repeatedly moving the cane back and forth. The obstruction can only be detected if the cane touches it detection range of a normal cane is very limited depending on the length size of the cane, which is around 1.2 meters (Santos et al, 2021). Due to this, the user may not receive any early warning of obstacles that are far from the user and may not be able to detect high obstacles such as tree branches. BVIPs could benefit from a detection range longer than 1.2 meters as early warning, this would allow them to be warned about obstacles earlier and improve safety, especially at waist level as the aim of the proposed device. Few recent studies discussed the limitation conventional white cane can only detect obstacles at ground level and cannot identify higher obstacles, such as those at head or trunk level, or objects hanging above (I. Khan et al., 2018) . (Manirajee et al., 2024) also point out that the cane does not provide early warnings, limiting a user's ability to avoid obstacles. Therefore, a wearable assist device for navigation with obstacle recognition features may be required.

Wearable technology refers to small-scale electronic instruments or microcomputers that are attached to the human body with a wireless connection. The wearable technology could monitor and examine a few functions such as biofeedback and other wide range of sensory functions. Two categories of wearable technology which are wearable computers (WC), which embed electronics into clothing, and smart textiles (ST), which are fabrics designed to react to environmental changes or user stimuli (Page, 2015). In the healthcare sector, wearable technology including bracelets or activity trackers such as Garmin and Apple Watch, focus on daily activity monitoring. It is commonly used due to its user-friendly and affordable features and functions such as step count, heart rate, and body temperature. There are also ingestible and insertable devices considered as wearable technology. The device is the size of a pill, filled with sensors, microcontrollers, and microprocessors, which are either ingested or inserted into the human body such as on, the "smart pill" to monitor internal reactions to medications (Godfrey et al., 2018). But, the various types of wearables developed for the healthcare sector make obtaining medical device certification a complex process that requires significant development and testing. Other than that, the complexity of current commercial wearable devices is also a barrier to application, especially for elderly individuals who have a strong preference for using traditional devices to detect obstacles (Godfrey et al., 2018; Ometov et al., 2021). As there is a limitation in using traditional devices in obstacle detection, this shows that wearable device development is important and could improve the safety and independence of the user.

A few types of available Electronic Travel Aids (ETAs) for navigating and mobility for visually impaired persons (BVIP) were recognized as some of the best inventions by TIME Magazine in 2019, utilizing ultrasonic sensors to detect obstacles above chest level and relay signals through vibrations. One such smart cane weighs approximately 360-370 grams, depending on its length, and features functions like GPS, voice feedback, and smartphone connectivity; however, it requires users to maintain a constant grip to fully utilize its capabilities (Kim & Ryu, n.d.). While the sensors are reliable and operate in nearly real-time, users must continuously hold the device while scanning their environment (Dakopoulos & Bourbakis, 2010; Dhivya et al., 2019). Another assistive device designed for orientation and mobility enables users to sense spatial information by emitting ultrasonic waves and tightening a wire as objects come closer (Bai et al., 2018). Although easy to learn, this 500-gram handheld device also necessitates continuous holding, presenting challenges for some users due to the limitations of human hearing, which may require extensive training to master (Dunai et al., 2014; Wai Zhao et al., n.d.). Furthermore, there is a cane, designed to assist users by altering their walking path when obstacles are detected, is criticized for its bulkiness and weight, making it cumbersome to carry (Dakopoulos & Bourbakis, 2010; A. Khan et al., 2018). Overall, even though these assistive devices offer advanced functionalities, they face limitations in portability, interaction stability, and complexity. There is a need to develop lightweight, user-friendly wearable tracking devices that enhance portability and ease of use for BVIP. Furthermore, this study also aims to evaluate the detection of sensors for various obstacles in both indoor and outdoor environments at different distances.

MATERIALS AND METHOD

This subtopic summarises the processes involved in developing the functional assessment of the proposed device. The schematic circuit for the obstacle detection and remote location tracking device was designed and simulated, with the connections for each selected component determined. After finalizing the schematic, the hardware components were assembled according to the circuit design. Next, functionality tests were conducted for both the obstacle detection and remote location tracking systems. The test results were collected and analysed for evaluation.

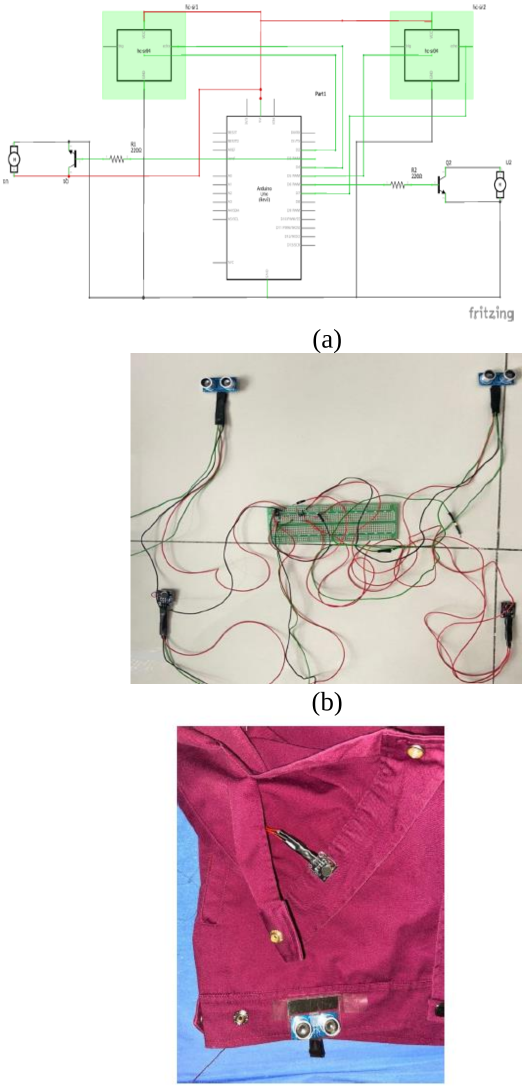
Software and hardware development.

The proposed wearable assistive device consists of a microcontroller, sensor, and also GSM/GPRS module. Few comparison studies that have been conducted in evaluating each component's suitability which contributes to a successful and complete system. In this study, the GSM module functions on the commonly utilised 2G and 3G network and is compatible with frequencies of 850/900/1800/1900 MHz and GPRS is to enable sending and receiving SMS messages, making phone calls, and establishing internet connectivity. Arduino Uno microcontrollers were used due to the market availability, cost-effectiveness, and lower power consumption which could extend the battery life and minimize the frequent recharging compared to the Raspberry Pi B+ and Arduino Nano.

In addition, Arduino Uno provides more input and output pins which able to be connected to more sensors and motors. The HC-SR04 sensor was selected and can detect the objects within 2 to 400 cm range, with accuracy up to mm compared to the infrared and camera sensors (Chandekar et al., 2017; Pai & Srinath, 2016; Parihar et al., 2020; Yohannan, 2020). HC-SR04 operates through a transmitter that emits a 40 kHz sound wave with a receiver that detects the reflected waves of the obstacles. The length between the user and the obstacle can be calculated below with the speed of sound is 340 m/s;

$$Distance\ (d) = \frac{time(t)\ x\ velocity(v)}{2} \quad (1)$$

The Pulse Width Modulation (PWM) vibration motor modules were chosen as they could increase the various speed controls through pulse-width modulation and be able to send haptic feedback supported by the 1000 mAh lithium-ion rechargeable 3.7 battery. Figure 1 (a) shows the schematic diagram of the components that were employed in the device of this project for the simulation. The components involved are Arduino Uno Rev3, GSM Module SIM 808, 2 pairs of HC-SR04 ultrasonic sensors, and PWM vibration motors. Four Ultrasound sensors were chosen because they are ideal due to their low cost, ease of use, and lightweight, sturdy design, offering quick response times (Joseph et al., 2023; Yu et al., 2014). They are highly efficient in dim lighting and can detect various objects, including transparent ones, making them versatile for multiple applications. Figure 1 (b) depicts the hardware components soldered permanently to ensure stable connections between components to be placed into a wearable jacket as in Figure 1 (c). The controlled parameter for this study is the testing durations for each session.



(a)

(b)

(c)

Fig. 1 (a) Schematic diagram; (b)Hardware development; and (c) Placement on a wearable jacket.

Functionality Test

The functionality tests involved are sensor detection tests and battery-operated performance tests to validate that the device able to work effectively and accurately.

Sensor detection test

The purpose of this test is to validate the accuracy and functionality of the sensors, ensuring it can deliver precise distance measurements for both units. This test is crucial for obstacle avoidance applications aimed for the users who are the blind or visually impaired individuals. The effectiveness of the both ultrasonic sensors were evaluated based on the activation of the PWM vibration motor when it detected obstacles at distances of 50 cm and 100 cm, as illustrated in Figures 2 (a) and 4 (b). For each sensor, two distance measurements were recorded under both trigger conditions, and average values were calculated. When the ultrasonic sensors identified an obstacle at 100 cm, the PWM vibration motor will activate and vibrating, noticed the user the presence of an obstacle within that range. The data collected during this experiment included precise distance measurements taken with a measuring.During the data collection process, the subject needs to walk towards the minimum mentioned distance and check for any vibrations from the motors. The distance was recorded at the moment the motor began to vibrate in response to respective obstacle at both distances and areas. At outdoor are the test was conducted on the three different types of surface obstacles which are bushes, wooden doors, and concrete walls, while at the indoor area, obstacles consisted of a plywood table, a concrete wall, and a wooden door. Each surface was tested twice, once with sensor 1 and once with sensor 2.

(a) (b)

Fig. 2 The setting sample process for the sensor detection test at 50 cm (a) indoor and (b) outdoor

Battery-Operated Performance Test

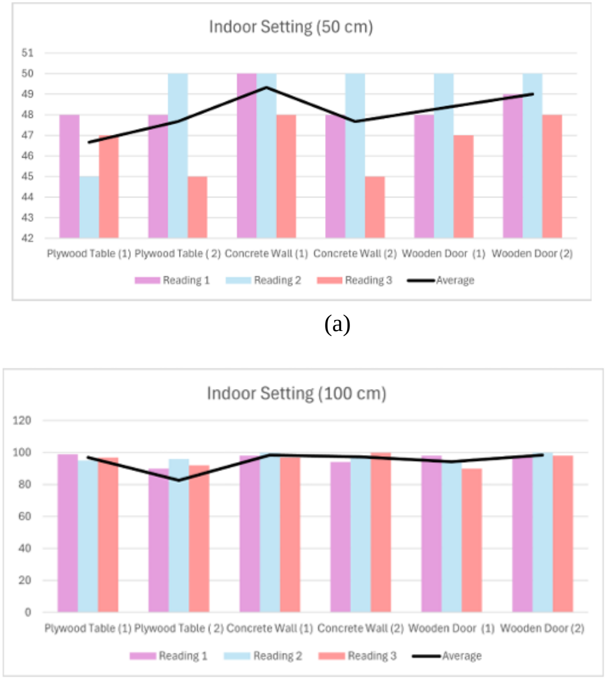
The battery-operated performance test was conducted to evaluate the duration for which the device's battery can maintain its power capacity. This assessment is crucial for this project as it measures the power efficiency of the wearable device, ensuring that its functionality and usability remain uninterrupted for the user just because of the to battery depletion. The test began with the device fully charged to 100%, and the time taken to recharge the battery from 10% to 100% was recorded. Subsequently, the prototype was activated and allowed to operate under standard conditions. The duration required for the battery to deplete to a low level, specifically 10% residual capacity, was recorded. This test was repeated multiple times to ensure the accuracy and reliability of the results. Finally, the collected data was used to calculate the average battery longevity, providing valuable insights into the battery's performance for user comfort and safety. Additionally, a battery-operated performance test was conducted to verify that the lifespan of the devices is suitable for daily use by users.

RESULT AND DISCUSSION

Several functionality tests were conducted and analysed to ensure the device's performance followed the minimum user requirement and operated well.

Sensor detection test

Sensor detection tests were conducted in two areas which are indoor and outdoor for both sensors. The measured distance could be acquired due to the emitting and receiving of the sound wave, thus indicating the obstacle in front of the ultrasonic sensor either 100 cm or 50 cm as in Figures 3 and 4. During the tests performed at indoors, both sensors showed different results, depending on the floor's type. As in Figure 3, the best results were obtained with concrete walls and wooden doors; the highest mark indicated 98.66% for the 50 cm trigger and 98.33% for the 100 cm trigger. Play wood obstacles indicated lower accuracy with 93.34 % and 82.67 % for 50 cm and 100 cm distances because of the difference in density of the material and surface texture that influenced the reflection of the sound waves and was less consistent. Obstacles (1) recorded by sensor 1 while obstacles (2) recorded by sensor 2.

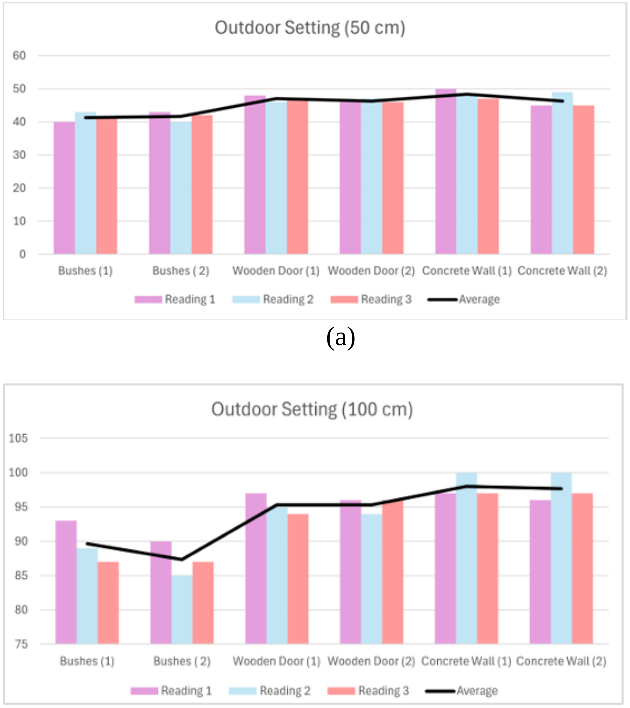


(a)

(b)

Fig. 3 The sensor detection data of various obstacles at different distances; (a) 50 cm and (b) 100 cm at indoor.

For outdoor settings, the obstacles are bushes, wooden door, and concrete wall. Figure 6 shows the lowest distance accuracy for 50 cm and 100 cm distance of the bushes obstacle with 82.60% and 87.30%. The highest accuracy was recorded by the concrete wall obstacle with 96.66% for the 50 cm distance and 98.0 % for the 100 cm distance. The efficiency of the ultrasonic sensor to detect the bushes' obstacles lower compared to the concrete wall and wooden door. This might be due to the softness of the bushes which can absorb more of the sound waves, while the concrete wall can reflect the sound wave better as its surface is denser and smoother. The wooden door resulted in consistent output since its surface allowed the stable reflection of the sound wave compared to the others. This shows that the ultrasonic sensor could be performed better and more effectively in detecting hard, reflective surface obstacles as agreed in the previous study (Dvorak et al., 2016). The variation observed in the results of Figure 5(a) and Figure 5(b), and the opposite pattern in Figure 6(a) and Figure 6(b), is due to the different test locations—indoor for Figure 5 and outdoor for Figure 6. Environmental factors like lighting, space, and obstacles can affect the performance of the ultrasonic sensors, with indoor areas generally providing clearer results than outdoor environments (Panda et al., 2016).



(a)

(b)

Fig. 4 The sensor detection data of various obstacles at different distances; (a) 50 cm and (b) 100 cm at outdoor.

Battery operation performance test

The assessment of the battery-operated device focused on the capacity of the battery can effectively operate before its performance declines. A cycle life test was conducted to evaluate the battery's lifespan by repeatedly charging and discharging it to mimic real-world use. The battery life cycle is the total number of times a battery can be charged and discharged before its capacity falls below 80% of its original level. Usage time varied across cycles based on the number of obstacles detected; more obstacles typically led to shorter usage times and the battery will be drained faster. This test was carried out over three cycles using a 1000 mAh lithium rechargeable 3.7 V battery. Table 1 indicates that the battery could fully discharge in about 7 hours and 45 minutes before needing a full recharge.

Table 1 Test for battery performance

Charging Duration	Usage Duration	Total Charging Time	Total Usage Time
6.30 PM – 7.15 PM	8.00 PM – 2.20 AM	45 mins	380 mins
9.00 PM– 9.40 PM	10.10 AM – 4.10 PM	40 mins	360 mins
1.00 PM – 1.45 AM	11.00 AM - 6.00 PM	45 mins	420 mins

The device's circuit was designed to integrate with the GSM SIM 808 module for remote location tracking, allowing the user to easily share their location by pressing a button. This would send the device's coordinates (latitude and longitude) directly to a caretaker's phone number. However, issues arose with the GSM SIM 808 module integration, primarily due to hardware problems, which prevented successful integration. The main issue with the GSM SIM 808 module was related to the component itself, not the algorithm. Despite several attempts to use different full codes to make the module work as intended, the codes were confirmed to be correct through detailed research. Further investigation is required to resolve the hardware issue and find an appropriate solution.

CONCLUSION

In conclusion, this project successfully developed a wearable obstacle detection device for blind and vision-impaired persons (BVIP). The device employed the Arduino Uno as the microcontroller, the ultrasonic sensor as the input, and the PWM vibration motor as the output source to alert the user. This device was specifically designed to be wearable with a jacket to be worn by the users which could assist the BVIP in moving and navigating around safely. This device could be used without the use of the walking cane or as a secondary aid to the walking cane to be used by the users. The sensor detection test showed that this device can be used either in outdoor or indoor areas and will be highly efficient for obstacles with hard surfaces and reflective effects. Furthermore, the output of the battery operational longevity test showed good agreement in ensuring the device function and usability were sustained despite the battery's lifespan limitation. Overall, the wearable navigation assistive device for obstacle detection could increase the independence and quality of life for BVIP. The user could attach the developed device to any wearable clothing every day to ease their daily activities. A potential improvement for the future is adding advanced sensors to enhance the system's functionality. Integrating LiDAR (Light Detection and Ranging) sensors is recommended, as they offer more accurate distance measurements and a wider range than traditional ultrasonic sensors.

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