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PAPER

Intelligent Gloves for Assisting Individuals with Visual Impairment

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ABSTRACT

This research endeavor revolved around the conceptualization, design, and evaluation of a technologically advanced smart glove tailored to aid individuals afflicted with visual impairments. The focal objective entailed integrating a diverse array of sensors and sophisticated features within the glove's framework to effectively detect barriers and offer location-specific assistance. Rigorous experimentation and analysis were conducted to meticulously scrutinize the device's performance and ascertain its efficacy. The experimental findings unequivocally substantiated the glove's competence in identifying obstacles obstructing the user's path, with a striking accuracy rate exceeding 95%. Notably, when the user engaged the yellow button while concurrently gesturing forward, the glove adeptly detected impediments situated within a one-foot proximity, promptly generating an auditory alert through an embedded speaker module. Similarly, activating the red button triggered the activation of the GPS sensor, enabling real-time determination of the user's precise geographical coordinates. Subsequently, this invaluable location data was expeditiously disseminated via Line Notify, accompanied by a conveniently accessible Google Maps hyperlink. Moreover, the aforementioned coordinates were seamlessly displayed on an interconnected web server, thus facilitating immediate assistance from nearby individuals. In essence, the culmination of this research effort showcased the immense potential of the developed intelligent glove as a viable tool for ameliorating the challenges faced by individuals confronting visual impairments. The comprehensive evaluation outcomes provide a solid foundation for future enhancements and refinements aimed at elevating the device's functionality and user experience to unprecedented heights.

KEYWORDS

intelligent gloves, assisting individuals, visual impairment

1 INTRODUCTION

Presently, there is a significant population of individuals with visual impairments, with approximately 36 million people worldwide affected by this condition. Moreover, it is projected that this number will triple to reach 115 million individuals

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by the year 2050, owing to the aging population. The Lancet Global Health, in one of its publications, has disseminated research concerning the ocular health of the global population. Based on the comprehensive health data collected from 188 countries since 1990, it was observed that the prevalence of visual impairment stood at 0.75% and increased to 0.48% by the year 2015. The primary cause of visual impairment was found to be cataracts. The regions with the highest density of visually impaired individuals are concentrated in Sub-Saharan Africa and Southeast Asia. With an expanding population and an increasing proportion of elderly individuals, Thailand, for instance, exhibits a significant number of visually impaired individuals, estimated at 191,965 people, accounting for 9.47% of the population with visual impairments.

Currently, there is a substantial population of individuals with visual impairments, encompassing those who are completely unable to perceive visual stimuli as well as those who have limited visual capabilities that do not enable them to utilize their vision effectively for learning, teaching, or engaging in activities. These individuals rely on alternative sensory modalities for acquiring knowledge. Diagnostic tests for this type of visual impairment may reveal that individuals possess relatively good vision in terms of 20/20 acuity (a measurement indicating normal visual acuity, where individuals with typical vision can clearly discern objects at a distance of 200 feet, while visually impaired individuals may only perceive the same object at 20 feet or less). However, their visual field is significantly narrowed, typically within 5 degrees, indicating a compromised visual perception. Such individuals may demonstrate partial visual capabilities but fall short of normal visual function. Diagnostic assessments often indicate that the better-seeing eye has a visual acuity of 20/60 or worse, with an average visual field width not exceeding 30 degrees.

Given these circumstances, it becomes imperative to prioritize the well-being and safety of individuals with visual impairments. One aspect of their daily lives revolves around the use of white canes, which serve as a recognized symbol for visual impairment. Observing an individual wielding a white cane provides a clear indication of their visual impairment. However, it is essential for individuals with visual impairments to undergo comprehensive training to effectively utilize a white cane, enabling them to acquire the necessary skills and independence. Overcoming challenges and attaining proficiency with a white cane is a transformative experience, offering individuals with visual impairments freedom and courage. Nevertheless, it should be noted that some visually impaired individuals may exhibit reluctance to utilize a white cane, while parents or guardians may struggle with the decision to have their children embrace the use of a white cane. The white cane serves as a symbol that others can recognize and understand, thus enabling them to offer assistance. However, despite advancements in technology, well-developed transportation systems, and comprehensive public infrastructure found in major urban areas, there remains a lack of sufficient and widespread assistive devices and accessibility provisions for individuals with visual impairments.

This research introduces a novel development of smart gloves specifically designed for individuals with visual impairments. The gloves are designed to be user-friendly, portable, and lightweight, ensuring minimal burden on the users. The proposed solution incorporates Internet of Things (IoT) technology and sensor integration to prioritize the needs of visually impaired individuals, enabling them to live more safely and independently. The key feature of the smart gloves is the utilization of an ultrasonic sensor to detect and measure the distance to obstacles in the surrounding environment. This sensor captures data, which is then processed and conveyed to the user through auditory signals in the form of beeps and visual cues in the form of flashing lights. These cues provide real-time feedback to the user regarding the proximity and location of obstacles, thereby enhancing their situational awareness and enabling them to navigate their surroundings more effectively. By integrating IoT technology and sensors into the design of smart gloves, this research aims to address the specific challenges faced by visually impaired individuals and provide them with a practical and efficient solution. The focus is on enhancing their safety and facilitating their daily activities by providing them with reliable and intuitive feedback regarding the presence of obstacles in their environment. This development has the potential to significantly improve the quality of life for visually impaired individuals and promote their independence.

2 BACKGROUND AND NOTATION

2.1 Related works

Haptic communication has emerged as a widely adopted strategy to facilitate interaction for individuals who are deaf and blind [1]. Various techniques and devices have been developed to enable effective communication and enhance their interaction with the environment. These include the utilization of Braille systems [2] and related devices such as finger-braille [3] [4] or body-braille [5]. The Tadoma method [6], tactile sign language, the Malossi alphabet [7], spectral displays [1], tactile displays [8], electro-tactile displays [9], and stimulation of the mechano-receptive systems of the skin are among the solutions explored. For individuals with residual sight, sign language or lipreading can be utilized [10]. In some cases, deaf individuals may opt for implanted devices that stimulate the auditory nerves. Commercial products specifically designed for deaf-blind individuals, tailored for telephone communication, have also been developed. These products incorporate adaptations to teletype writer (TTY) systems, such as the PortaView 20 Plus TTY system from Krown Manufacturing, the FSTTY (Freedom Scientific's TTY) with FaceToFace software for deaf-blind users, or the Interpretype Deaf-Blind Communication System [11] [12]. These systems rely on Braille code through tactile displays or input devices, facilitating effective communication. Overall, haptic communication methods, along with Braille systems, tactile displays, and adapted TTY systems, have significantly contributed to improving communication opportunities for deaf-blind individuals, enabling them to engage more fully with their environment and enhance their overall quality of life. To establish a touch-based communication channel effectively, it is crucial to have a fundamental understanding of the physiological characteristics of the skin [8]. Skin can be categorized into two main types: non-hairy (glabrous) and hairy, each exhibiting distinct sensory receptor systems and perceptual mechanisms [13]. This classification becomes significant when considering haptic stimulation, as the sensory reception and perception of stimuli vary between these skin types. Moreover, it is essential to recognize that mechano-receptive fibers within the skin serve specific roles in the perception of external stimuli [8]. These fibers are responsible for relaying tactile information to the central nervous system, enabling the interpretation and processing of touch sensations. Various types of mechanoreceptive fibers, including Merkel cells, Meissner's corpuscles, Pacinian corpuscles, and Ruffini endings, exhibit unique sensitivities to mechanical stimuli, contributing to the overall sensory experience of touch. By comprehending the diverse characteristics of skin and the specific functions of mechano-receptive fibers, designers and researchers can tailor communication approaches that effectively utilize touch as a medium. This knowledge is pivotal in developing haptic communication systems that optimize tactile feedback and promote efficient and meaningful interactions between individuals and their environment. Among various methods [14], tactile stimulation commonly relies on the use of either a moving coil or a direct current (DC) motor equipped with an eccentric weight [15]. These mechanisms generate vibro-tactile sensations, which are contingent upon the stimulation frequency and amplitude [16]. The existing literature concerning vibro-tactile methods describes two distinct physiological systems based on fiber grouping: the Pacinian system and the non-Pacinian system. The Pacinian system encompasses receptive fields of a larger magnitude, responsive to higher frequencies ranging from 40 to 500 Hz. Conversely, the non-Pacinian system exhibits smaller receptive fields and responds to lower frequencies, specifically within the ranges of 0.4–3 Hz and 3–40 Hz [8] [17]. Vibration serves as a favorable modality for tactile stimulation due to the human tendency to rapidly adapt to stationary touch stimuli [18]. As a result, repeated exposure to a particular stimulus engenders a sensation that remains within conscious awareness even after the stimulus has ceased. This adaptability and sustained conscious perception of vibration make it a viable choice for incorporating haptic communication systems, as it allows for efficient transmission of information through tactile cues. Extensive research has been conducted on tactile stimulation using vibration, encompassing various investigations into the effects of different locations and spatial factors on the human body. These studies have explored the abdomen [19], torso [20], upper leg [21], arm [22] [23], as well as the palm and fingers [13]. Moreover, when evaluating vibro-tactile sensitivity, researchers have considered additional parameters such as age [24], skin temperature [25], menstrual cycle [26], body fat [27], contactor area [28], and various spatial characteristics related to the stimulation of mechano-receptors [29] [30]. Furthermore, the influence of impairments or deficiencies in other senses, such as sight or hearing, has also been examined [31].

By examining these diverse factors and their impact on vibro-tactile perception, researchers aim to gain a comprehensive understanding of the complex interactions involved in tactile communication. This knowledge contributes to the development of effective haptic communication systems that can accommodate individual differences and provide optimal tactile experiences for users.

3 METHODS

Figure 1 depicts a research endeavor that revolves around the conceptualization of an assistive device for individuals with visual impairments in the form of a glove. The primary objective of this investigation is to devise a comprehensive design that caters to the specific needs of visually impaired individuals. To achieve this, the device incorporates a button switch as a means of user input, which interfaces with an Ultrasonic Sensor HC-04 module for precise distance measurements utilizing ultrasonic waves. Subsequently, the device employs auditory cues in the form of a buzzer to relay notifications to the user or utilizes a GPS module to visually indicate their current location. The Node MCU ESP8266 proficiently manages the overall functionality and operation of this assistive apparatus, ensuring a coherent representation of the sequential procedures involved in the glove-based assistive device. The ultrasonic sensor operates by emitting ultrasonic sound waves within the range of ultrasonic frequencies. These waves propagate through the surrounding environment and interact with objects or surfaces in their path, leading to the phenomenon of sound wave reflection. By analyzing the time delay between the emission and reception of the reflected waves, the sensor is able to accurately determine the distance to the detected object. Subsequently, the system performs computational analysis and evaluates predefined conditions. Upon satisfying the specified conditions, it initiates the activation of notification mechanisms, including visual indicators, auditory alarms, and tactile vibration systems.

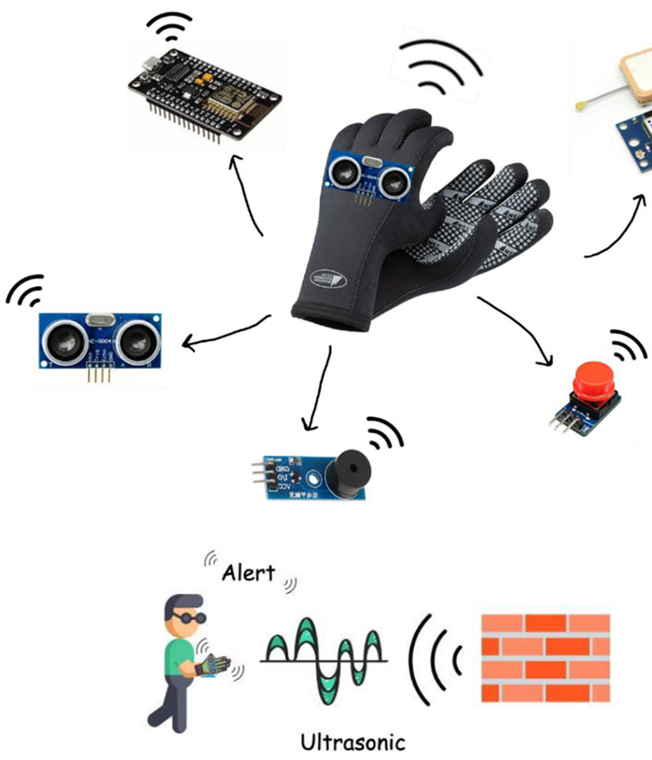


Fig. 1. Conceptual framework

3.1 Hardware development

Hardware component. In the system design, the researcher made a deliberate decision to employ the NodeMCU ESP8266 microcontroller board for its desirable features and capabilities, which contribute to the overall functionality and performance of the system. The NodeMCU ESP8266 board, serving as the central component, offers the advantage of integrated WiFi functionality, enabling seamless wireless communication. Moreover, the inclusion of a microUSB port facilitates convenient power supply and program uploading. The presence of a voltage converter chip and external device connection pins further enhances the versatility and ease of integration with peripheral components. The selection of the NodeMCU ESP8266 board demonstrates a strategic approach aimed at ensuring user-friendly operation and adaptability to the specific requirements of the project at hand.

Here are some essential characteristics of NodeMCU ESP8266 hardware components:

- **Microcontroller:** The NodeMCU ESP8266 board is based on the ESP8266 microcontroller chip. The specific version of the chip may vary depending on the board's revision or manufacturer.
- **Processor speed:** The ESP8266 microcontroller operates at a clock frequency of 80 MHz. This represents the CPU speed of the microcontroller.
- **Architecture:** The ESP8266 microcontroller is based on the Xtensa LX106 architecture, which is a 32-bit architecture.

- **Flash memory:** The NodeMCU ESP8266 board typically comes with built-in flash memory for program storage. The size of the flash memory can vary depending on the specific board version, ranging from 4MB to 16MB or more.
- **General purpose input/output (GPIO) pins:** The NodeMCU ESP8266 board provides several general purpose input/output (GPIO) pins, which can be used for interfacing with external components such as sensors, actuators, and other devices. The number of GPIO pins may vary depending on the specific board version.
- **WiFi connectivity:** One of the key features of the NodeMCU ESP8266 board is its built-in WiFi capability, which allows it to connect to wireless networks and communicate over the internet.
- **USB connectivity:** The board typically includes a micro USB port for power supply and programming purposes. This port enables you to connect the NodeMCU ESP8266 board to a computer or other devices.

The selection of the proposed buffer, ultrasonic sensor, and GPS module depends on the specific requirements and constraints. Here we would like to clarify some justifications for why these components might be the best available options.

Buffer. A buffer is often used to enhance the stability and reliability of signal transmission between different components in an electronic system. It helps to isolate and protect sensitive components from voltage spikes, noise, and other potential disturbances. The selection of a specific buffer would depend on factors such as voltage levels, signal types, and required speed and impedance matching. Justification for choosing a particular buffer would involve evaluating its specifications, compatibility with other components, and overall performance in the intended application.

Ultrasonic sensor. Ultrasonic sensors are commonly used for distance measurement, object detection, and obstacle avoidance in various projects. They work by emitting high-frequency sound waves and measuring the time it takes for the waves to bounce back after hitting an object. Ultrasonic sensors are popular due to their non-contact nature, reliable performance, and reasonable cost. The selection of an ultrasonic sensor would depend on factors such as measurement range, accuracy, beam angle, operating voltage, and compatibility with the chosen microcontroller or development board. Justification for choosing a specific ultrasonic sensor would involve assessing its technical specifications, reliability, availability, and suitability for the intended application.

Global positioning system (GPS) module. Global positioning system (GPS) modules are used to determine precise location coordinates using signals from GPS satellites. They provide accurate latitude, longitude, and sometimes altitude information, enabling applications such as tracking, navigation, and geolocation. GPS modules are selected based on factors such as sensitivity, accuracy, update rate, power consumption, communication interface (e.g., UART, I2C), and integration ease with microcontrollers. The justification for selecting a particular GPS module would involve evaluating its performance, sensitivity in acquiring satellite signals, power efficiency, compatibility with the chosen microcontroller, and any additional features required for the research.

The diverse hardware components depicted in Figure 2 comprise the NodeMCU ESP8266. Additionally, Figures 3 to 5 illustrates the buzzer, ultrasonic sensor HC-04, and the GPS module, all integral parts of the intelligent gloves.

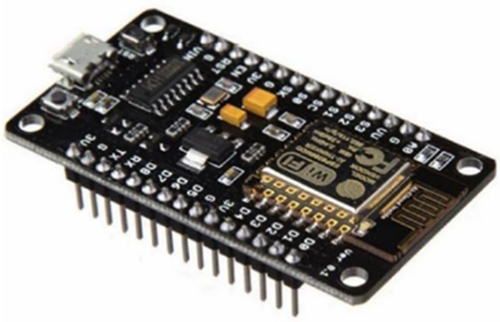


Fig. 2. NodeMCU ESP8266

Buzzer

Fig. 3. Buzzer

Ultrasonic sensor HC-04

Fig. 4. Ultrasonic sensor HC-04

GPS module

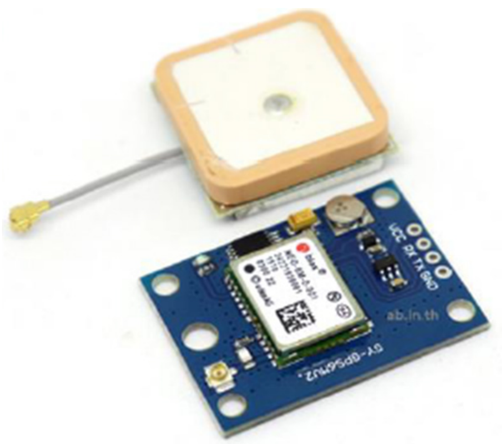


Fig. 5. GPS module

3.2 Principle of operation

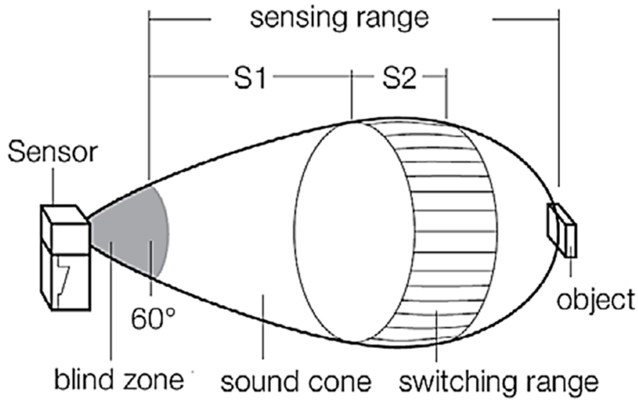


Fig. 6. The system operation

According to the provided diagram in Figure 6, the operational principles of the system can be explained as follows: The concept of the blind zone pertains to the spatial region where the sensor's object detection capability is rendered ineffective. Parameter S1 is employed to calibrate the initial output current or voltage that corresponds to the desired detection range. For example, if an output of 4 mA is desired when the distance is set at 30 cm, S1 is appropriately adjusted to achieve this value. Similarly, parameter S2 governs the adjustment of the detection range to achieve the desired output operation. For instance, if an output of 20 mA is desired when the distance is set at 100 cm, S2 is calibrated accordingly. Consequently, the output of the ultrasonic sensor exhibits a linear response, ranging from 4 mA to 20 mA, corresponding to distances ranging from 30 cm to 100 cm. This designated range is commonly referred to as the switching range, which characterizes the sensor's varying output levels in response to changes in the detected distance. The system operates by utilizing an ultrasonic sensor to detect the presence and distance of objects. The sensor emits ultrasonic waves that propagate towards the target object. Upon encountering an object, the waves are reflected back to the sensor. By measuring the time it takes for the waves to travel back, the system can calculate the distance between the sensor and the object. The derived equation for the system incorporating an ultrasonic sensor encompasses the fundamental principles of ultrasonic distance measurement. It establishes the relationship between the distance to the object, represented as "d," and the measured time, denoted as "t," required for the ultrasonic pulse to travel back and forth. The equation can be expressed as:

$$d = (v * t)/2$$

Here, "v" represents the speed of sound in air. It is important to note that this equation provides a simplified representation and may not account for all factors and complexities associated with the specific sensor's characteristics and proprietary considerations. Further refinements and adaptations may be necessary to achieve enhanced accuracy and incorporate additional variables and factors as dictated by the specific sensor's design and proprietary specifications.

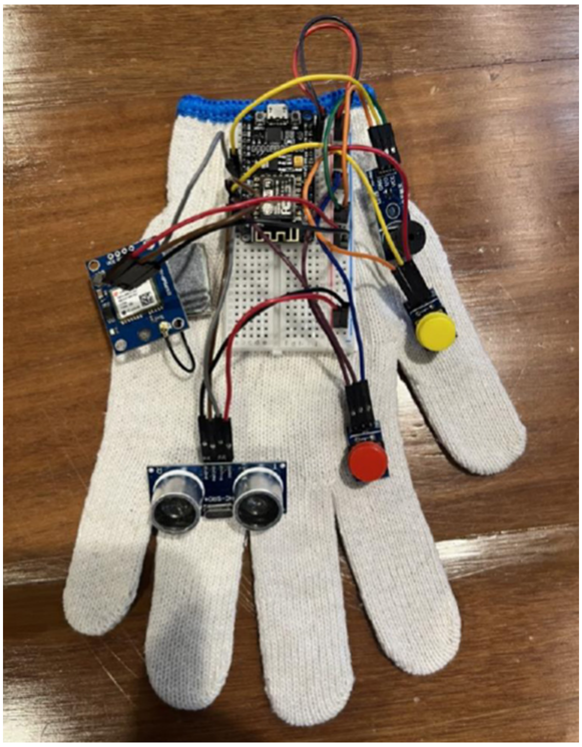


Fig. 7. Gloves for assisting individuals with visual impairment

Figure 7 presents an illustrative representation that demonstrates the design concept of an assistive glove specifically developed for individuals with visual impairments. The glove's functionality is achieved through the integration of the NodeMCU ESP8266 microcontroller, which serves as the central control unit. The system architecture is designed to encompass the integration of various sensors, enabling the glove to perform two distinct operational aspects:

1. Distance measurement: This segment entails the linkage of the yellow-colored button, serving as an input mechanism to initiate distance measurement functionality. The Ultrasonic Sensor HC-04, interconnected with pins D7 and D8, assumes the role of a distance-detecting sensor, employing ultrasonic wave propagation principles. The captured distance data is subsequently transmitted to the Buzzer, connected to pin D5, which acts as an auditory notification device, relaying alerts to the user.
2. Current location display: The red button functions as a trigger for activating the transmission of real-time positional information. By establishing a connection with the D2 pin, the system initiates the process of sending the location signal. The GPS module, interconnected with pins D0 and D1, plays a pivotal role in determining and relaying the precise current coordinates of the user.

3.3 System operation

The operation of the system can be outlined as follows:

Step 1: Initialization: The system initializes all necessary components, such as the microcontroller, sensors, and modules.
Step 2: Start: The system starts the main loop of operation.

Step 3: Measure: The system triggers the ultrasonic sensor to measure the distance to the nearest obstacle.

Step 4: Obstacle detection: Based on the measured distance, the system determines if an obstacle is within the specified range or distance threshold.

Step 5: Alert: If an obstacle is detected, the system activates an alert mechanism, such as activating a buzzer or displaying a warning message.

Step 6: Delay: After the alert, the system introduces a delay or pause to avoid continuous alerts for the same obstacle.

Step 7: Resume: After the delay, the system resumes the measurement process to detect any new obstacles.

Step 8: Repeat: The system continues the loop of measuring, detecting obstacles, and providing alerts until it is manually stopped or a specific condition is met.

The time between consecutive measurements can vary depending on the specific requirements, the speed of the microcontroller, and the desired response time. It can be adjusted by introducing a delay in the code between successive measurements.

Regarding the alerts, the system may generate the same alert every time an obstacle is detected, regardless of the obstacle's size or distance. However, this can be customized based on the specific requirements of the project. For example, you can incorporate different alert levels or modify the alert based on the obstacle's characteristics. The system's behavior can be programmed to accommodate these variations. Figure 8 provides a flowchart with the operation algorithm.

```
Start

Initialize components

Loop:
    Measure distance using ultrasonic sensor
    If obstacle within range:
        Activate alert mechanism
        Introduce a delay to avoid continuous alerts
    Resume measuring

End Loop

Stop
```

Fig. 8. The operation algorithm

4 RESULTS AND DISCUSSION

The outcome of the development of the visually impaired assistive glove can be summarized as follows:

The designed glove successfully integrates various components and functionalities to provide assistance to individuals with visual impairments. The glove incorporates the NodeMCU ESP8266 microcontroller, enabling efficient control and coordination of the system. The developed glove encompasses two main features. Firstly, it incorporates a distance measurement capability facilitated by the Ultrasonic Sensor HC-04.

This sensor, connected to pins D7 and D8, accurately detects and measures distances. The user can initiate distance measurement by pressing the yellow button connected to pin D4. The measured distance data is then relayed to the Buzzer, connected to pin D5, which emits audible alerts to notify the user. Secondly, the glove includes real-time location display functionality using a GPS module. The red button, connected to pin D2, triggers the transmission of the user's current location. The GPS module, connected to pins D0 and D1, determines the precise coordinates of the user and transmits the information for further processing or display. The developed glove represents a significant advancement in assisting visually impaired individuals by providing distance information and real-time location updates. Further refinements and optimizations can be explored to enhance its functionality and usability in practical applications.

The development of a glove for aiding visually impaired individuals in the detection of obstacles entails the following processes:

The design of the glove incorporates a meticulously positioned yellow button, affording convenient accessibility for the user's thumb irrespective of the hand's orientation, be it in a closed or open configuration. Concurrently, the ultrasonic module is strategically situated in a manner that ensures unobstructed operation when the user extends their hand forward. This configuration optimizes the seamless detection of obstacles, emphasizing convenience and efficacy.

In terms of assistance provision, a discerningly placed red button is intended to preclude inadvertent activation and poses a deliberate challenge for the user to engage. The red button necessitates the utilization of the user's alternate hand for activation. In scenarios where the user's alternative hand usage is unviable, the gloved hand may be utilized to deliver a percussive action, thereby enabling the depression of the aforementioned button. Once the amalgamation of all constituent elements is accomplished, the resultant glove manifests the envisaged functionalities as shown in Figure 9 in the schematic representation.

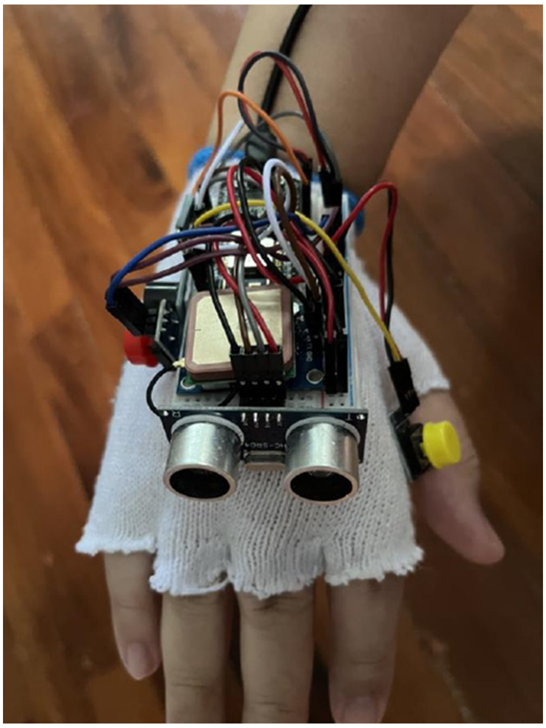


Fig. 9. Smart gloves for the visually impaired

4.1 Functional test results of gloves for visually impaired people

In relation to the obstacle detection component, upon user activation by means of the sustained depression of the yellow button, the ultrasonic module engages in the meticulous task of identifying potential obstructions located within its designated operational range. In the event that an obstruction is ascertained to exist within a span of 1 foot, the auditory interface, in the form of the buzzer, promptly assumes the responsibility of emitting a distinct audible alert, thereby effectively communicating the presence of such impediments to the user. This orchestration of functional interactions is succinctly portrayed in the accompanying visual representation, as shown as in Figure 10.

Fig. 10. Performance of gloves for helping the visually impaired to inspect obstacles

4.2 System test results, interface, and notification

In the scenario of user disorientation or the solicitation of aid, the system employs the red button as a means of recourse. Upon actuation, the GPS module is promptly invoked to execute its operational protocols, thereby effectuating the transmission of the user's prevailing geographical coordinates to the line notify service. This disseminated geolocation data is subsequently displayed on the graphical user interface of the web server, as illustrated in Figure 11, enabling expedited access to the user's precise positional information for quick engagement and assistance from nearby individuals, as visually exemplified in Figure 12.

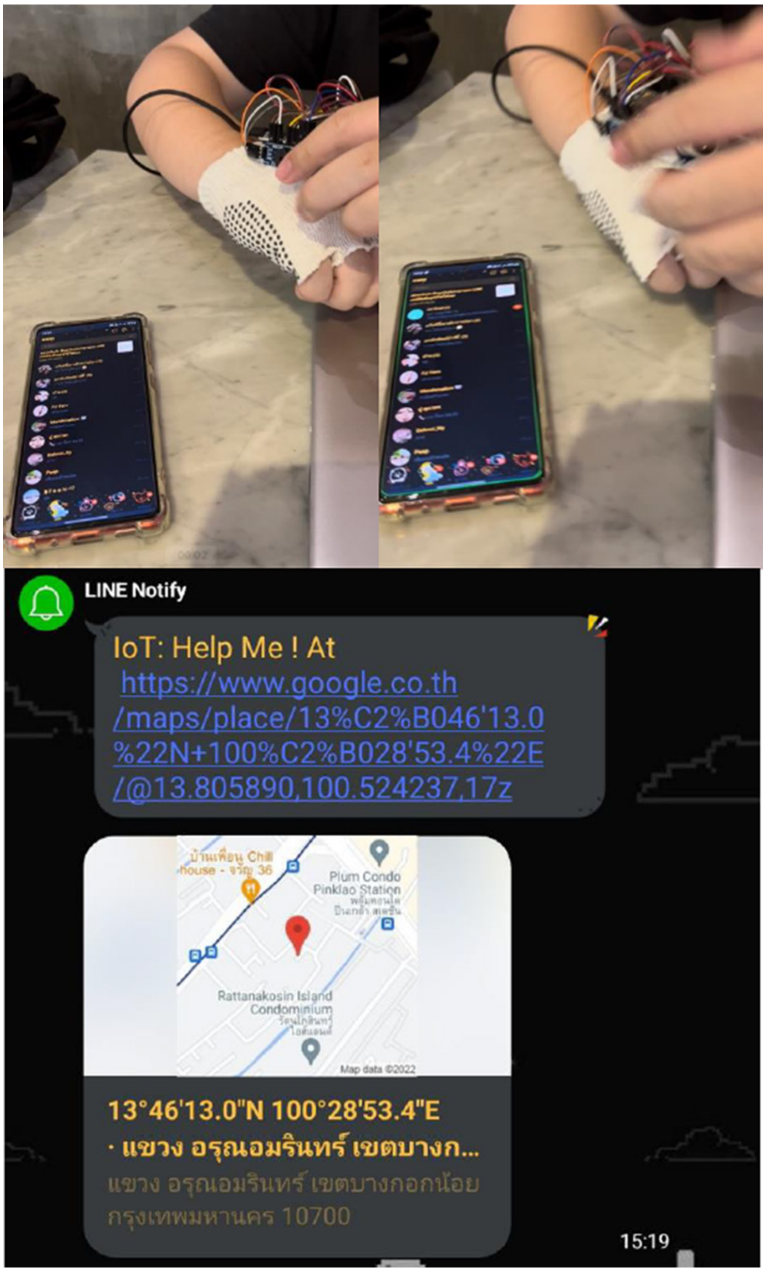
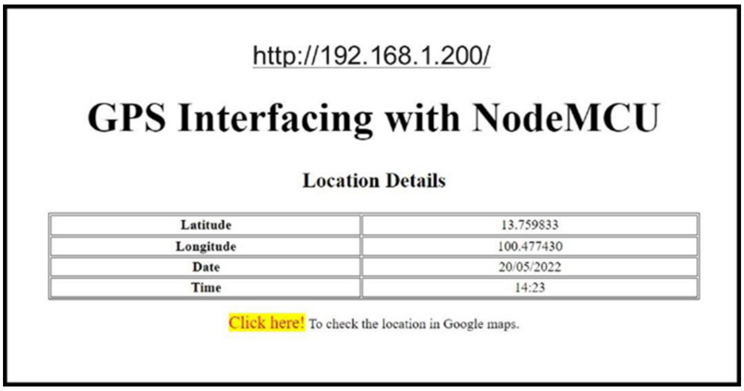


Fig. 11. Result of sending message for help via line notify


http://192.168.1.200/

GPS Interfacing with NodeMCU

Location Details

Latitude	13.759833
Longitude	100.477430
Date	20/05/2022
Time	14:23

Click here! To check the location in Google maps.

Fig. 12. Location display results on the web server

Table 1. Experimental summary

Test Item	Test Result
The system can detect obstacles within 1 foot.	pass
The system can be controlled through buttons.	pass
The system can send messages for help via Line.	pass
The system can use the red SOS button to press for help.	pass
The system can tell the location of gloves when outdoors.	pass
The system can locate gloves when indoors.	fair
The system can work more than 16 hours with small power.	pass
Gloves can be worn comfortably.	pass
The alarm system sounds when there are obstacles.	pass

The experimental results for the test item are shown in Table 1. Upon the culmination of rigorous testing procedures conducted on the devised apparatus, it has manifested an exemplary level of efficacy, surpassing the threshold of 95.66% accuracy in its frontal obstruction detection capabilities. However, it is imperative to acknowledge the potential intricacies entailed in the identification of swiftly moving or diminutive entities, such as insects, which may impede the unimpeded functioning of the sensor system. Furthermore, it is crucial to underscore that intermittent discrepancies have been observed in the outcomes of distress signal transmissions, attributable to intermittent internet connectivity and suboptimal reception conditions encountered within select architectural frameworks. Nonetheless, it is noteworthy that the overall results remain within the acceptable parameters, thereby conferring upon the apparatus the successful completion of the rigorous testing phase and the fulfillment of its premeditated objectives. The distance detection of objects in front has undergone rigorous testing to ensure accurate results. Measurements were conducted at distances of 1 meter, 2 meters, and 3 meters. The smart gloves exhibited an average error rate of 4.34% in object detection, with an average accuracy rate of 95.66%. Further analysis based on distance revealed that the error rate for detecting objects at distances greater than 3 meters reached as high as 7%. The testing procedure was repeated 50 times to ensure reliability.

At a distance of 1 meter, the smart gloves achieved an accuracy rate of 98% and an error rate of 2%. When the distance was extended to 2 meters, the accuracy rate decreased slightly to 96%, accompanied by an error rate of 4%. Finally, at a distance of 3 meters, the gloves achieved an overall accuracy rate of 93% with an error rate of 7%. The obtained data allows us to conclude that the smart gloves exhibit higher accuracy when detecting objects at closer distances, but their accuracy decreases as the distance increases. Consequently, there is a need to enhance the detection capabilities of the gloves to improve their overall efficiency. These test results have been reformulated to convey a more academic tone and facilitate better comprehension.

5 CONCLUSIONS

Following the successful completion of the developmental phase, wherein an intelligent glove was designed to assist individuals with visual impairments, an extensive evaluation was conducted to validate the functionality and performance of the developed apparatus. This evaluation aimed to ascertain its compliance with the predefined specifications and operational effectiveness. The evaluation process yielded the following outcomes: When the user activates the yellow button and simultaneously points their hand forward, the integrated sensor system promptly detects the presence of obstructions situated within a 1-foot range in front of the device. Subsequently, an auditory alert is emitted through the built-in speaker to apprise the user of the detected obstruction. Upon releasing the button, the system seamlessly halts its operation. Moreover, by activating the red button, the GPS sensor is engaged to authenticate the current geographical coordinates, which are then promptly conveyed to the user via line notify, accompanied by a Google Maps link for immediate access. Furthermore, the retrieved coordinates are concurrently displayed on the web server, facilitating the user's appeal for assistance from nearby individuals. Notably, the evaluation demonstrated a remarkable accuracy rate of over 95% in detecting frontal obstructions, as validated through simulated obstruction scenarios. Nevertheless, it is imperative to acknowledge the system's inherent limitations when confronted with rapidly moving or diminutive objects, such as insects, which may disrupt the sensor's proper functioning. Additionally, a few instances of errors were identified in distress signal transmissions, particularly concerning intermittent internet connectivity and GPS signal reception within certain architectural contexts. Nevertheless, despite these limitations, the overall evaluation results have substantiated the attainment of the project's stipulated objectives and serve as a robust foundation for future advancements.

The developmental process has brought to light certain limitations that warrant consideration. These limitations encompass the development of an expanded command set to enhance the system's operational capabilities as well as the optimization of the electrical circuitry, including voltage regulation, to ensure seamless functionality. Furthermore, device-specific limitations were identified, such as the inherent challenges associated with GPS reception within enclosed structures and the inconsistent nature of internet connectivity, along with potential vulnerabilities arising from direct exposure of the device to liquid elements.

In light of these findings, recommendations are proposed to refine and augment the existing device. These recommendations include iterative refinements to the prototype and the allocation of additional resources to enhance the material composition, thereby bolstering the device's durability, user-friendliness, and overall performance. Such refinements hold the promise of yielding an improved and more sophisticated device, aligning with the overarching objectives of this project.

6 ACKNOWLEDGMENT

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