IoT-Based Obstacle Detection System for Visually Impaired Person with Smartphone Module

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***Abstract*—Visually impaired persons face several challenges in their daily lives. In many cases, they are usually dependent on others, making them less confident in an unfamiliar environment. Therefore, this article presents an IoT-based system that helps to detect obstacles and water puddles on their way. The system consists of a walking stick and an Android app from a third-party app. The walking stick is integrated with an ESP32 microcontroller, an ultrasound sensor, and an app for smartphones. The sensors gather information from the surroundings, and the ESP32 microcontroller detects the obstacle by processing the information. The communication between the ESP32 microcontroller and the smartphone is carried out through the MIT App Inventor. The smartphone application generates audible instructions to navigate the visually impaired persons properly. The results indicated that the developed system obtained an accuracy of about 99.54% at a distance of 250cm and 99.03% at a distance of 450cm. The system also sensed an obstacle angular position of up to 90°. Thus, it shows that this system has been very effective and efficient for visually impaired persons to navigate with precise voice instructions. Overall, the system developed would help visually impaired person independent lives safely, which will ultimately increase their level of confidence in an unfamiliar environment.**

***Index Terms*—visually impaired person, obstacle detection, Internet of Thing (IoT), smartphone, MIT app inventor**

I. Introduction

Visually impaired persons are classified as person with visual defects or completely blind. Visually impaired persons face many challenges in their daily life as eyes, the organs of vision, play a vital role in processing information from the environment [1]. Most visually impaired persons struggle in their daily life as it is not easy for them to travel or explore unfamiliar environment independently. In fact, they have to depend upon others such as friends, family or trained dog while traveling alone due to the restriction of visual and movement. Blindness is the imbalance of physiological and neurological elements called unconsciousness. However, with the help of modern science and technology, their struggle can be alleviated.

According to the World Health Organization (WHO), an estimated 36 million people in this world are totally blind and 217 million have moderate to severe vision problem. Most of the people having visual impairment are aged > 50 years and the rest are < 15 years [2]. Recent statistics revealed that the number of visually impairment person will increase due to the increment of the population and aging factor. In most cases, visually impaired people are dependent on a white cane or guide dog to perform daily activities. However, the white cane is restricted to provide tactile information due to its confined size while a guide dog cannot precisely provide information of a dangerous situation such as a hump on the road [3], [4].

Various works in technological innovation have been conducted in order to provide opportunities and more comfortable life for visually impaired person. Some of the electronic travel aids are based on sensors and actuators [5]-[8], computer vision, deep learning [9] and machine learning [10] which provide convenient interaction with environment. Devices developed are based on sensors or cameras that provide information about the surrounding by sensing the environment and notifying the user. The camera-based obstacle detection technology operates by capturing pictures using computer vision-based technique.

The proposed devices in this study may not be attractive-looking, but focus is given in the development of Internet of Thing (IoT) system using a smartphone module that is able to detect obstacles and water puddles. The system is designed with a combination of hardware and software that can detect static and moving obstacles. The system developed in this study is integrated with an ESP32 microcontroller and HC-SR04 PIR sensor. The sensors gather information from the surroundings, and the

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ESP32 microcontroller detects the obstacle by processing the information. The communication between ESP32 microcontroller and the smartphone is carried out through the MIT App Inventor. The IoT-based system for detecting obstacles and water puddle makes the navigation for visually impaired person more convenient.

II. Related Work

A large number of research works are conducted in order to assist visually impaired person in navigation. Initially, most of visually impaired person depended upon others such as trained dog and white cane as an assistance but with certain limitations. The white cane is known to be the most affordable assistant tools. However, it cannot accurately detect obstacles in which the user gets less time to react to any situations. A trained dog can be very expensive to some visually impaired person, and it may have chance to fall sick or hurt. Thus, these assistants are not so efficient. Several research has proposed methods to overcome this issue.

Shaha *et al.* [11] proposed a system in which they used a low latency communication algorithm to inform the user on the obstacle over different distances using different vibration and buzzing types. It also included a GPS module and an application module for real-time tracking. Shahira *et al.* [12] have developed a support system that detects the obstacle, identifies it and alerts the user via audio. An ultrasonic sensor was used to detect and measure the distance of the obstacle. Agrawal *et al.* [13] proposed a smart stick for blind and visually impaired people. Some electrical components such as sonar transducer, buzzer, GPS module, GSM module, RF module are integrated with the stick. It can detect obstacles located across from the user and give notifications via the buzzer. O'Brien *et al.* [14] proposed a cost-effective walking stick system that provides an alarm when it senses obstacles. A customized Printed Circuit Board (PCB) with a microcontroller organized all the sensors and motor. Sahoo *et al.* [1] have proposed a walking stick system, including a controller Raspberry Pi hardware and Android app module. The user is notified by vibration or alarm when obstacles or water are encountered.

Study on ESP32 microcontroller and MIT App Inventor is currently minimal which is described in detail as in the next section. Thus, this study will focus on the ESP32 microcontroller as an IoT application integrated with MIT App inventor for detecting obstacle and water puddles for visually impaired persons.

A. *ESP32 Microcontroller Module for the Internet of Things (IoT) Applications*

The Internet of Things (IoT) market has rapidly expanded in recent years in response to increased demand for communication and control for various devices and gadgets. IoT technology has a significant impact on people's behavior and lifestyle in professional and domestic environments. The critical requirement for modern IoT devices is to provide efficient connectivity to ensure reliable remote communication and data transfer in a wireless environment [15].

To further enhance the IoT and extend the reach of its application, IoT devices need efficient, cost-effective, and energy-efficient solutions. The small form factor is another requirement for an IoT unit, the smaller the unit's size and weight, the greater its applications. Each IoT-based unit consists of a microcontroller (μC) and a module for wireless switching (WiFi or Bluetooth), or a combination of both. The ESP32 system structure is explained in detail as in Fig. 1.

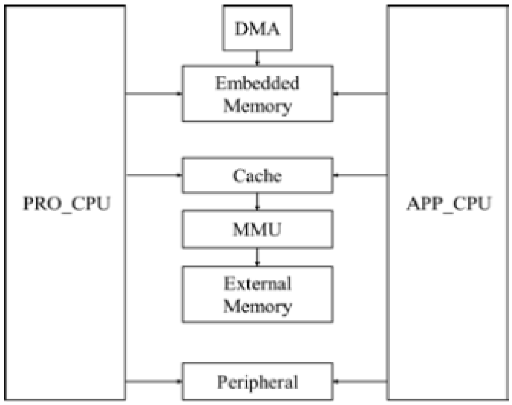


Figure 1. ESP32 system structure.

Maeir *et al.* [15] stated that the ESP32 programming language is C, which means that most API libraries are also available in C. Since this chip is open source, anyone can build an operating system for the ESP32, so there are solutions on the Internet to programme it in LUA or JavaScript. The high performance of the microcontroller is achieved through dual-core configuration and significant expansion of operational functionality. The microcontroller process flowchart is shown in Fig. 2. As a result, ESP32 is expected to play vital role in designing future IoT systems, especially for this study.

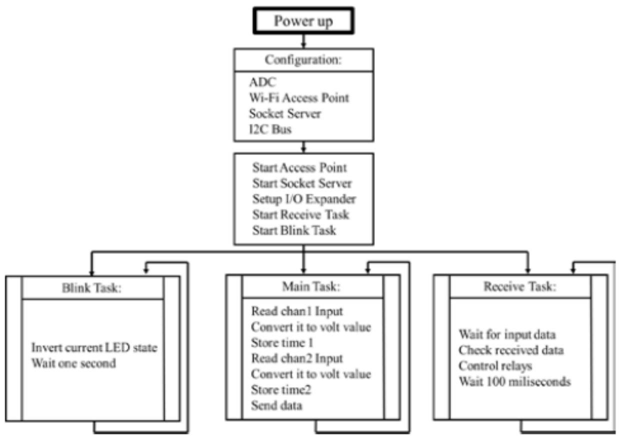


Figure 2. Microcontroller flowchart.

B. *Taxonomy of the Reviewed Walking Sticks*

A walking stick is set up according to specific techniques. For instance, some systems are designed using a combination of different technologies [16]. Consequently, based on existing methods, the walking stick that is developed can be divided into three categories. The reviewed walking sticks' taxonomy is depicted in Fig. 3, in which the works associated with the previously described criteria are outlined in [5]. Thus, in this study, we will develop an IoT combination of a sensor-based walking stick with a smartphone module.

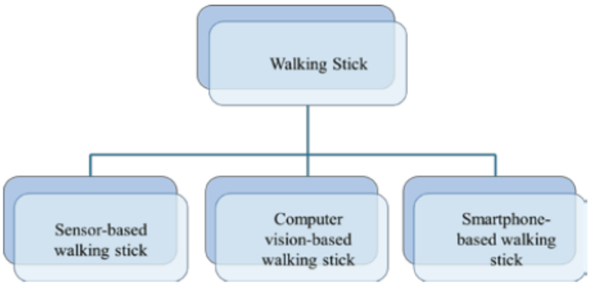


Figure 3. Taxonomy of the reviewed walking assistants for visually impaired persons.

III. METHODOLOGY

Method to construct the proposed system is divided into three phases which are prototype design and development, android application development using MIT App inventor, and the operation mode and data documentation.

In this study, an ultrasonic sensor is used for obstacle detection in front of the users. Another ultrasonic sensor is used to detect hole and datum on the ground or on the road. A PIR motion sensor is used for detecting the moving objects in front of the user. All the sensor data will be sent to the user's smartphone using a Bluetooth module. Then, MIT app inventor designed to scan and pair the device to communicate to the Bluetooth module of the ESP32. The user will be notified if there is an obstacle or a hole or a moving object in front of him/her by speech instructions from his/her smartphone. The block diagram of our proposed system is depicted in Fig. 4.

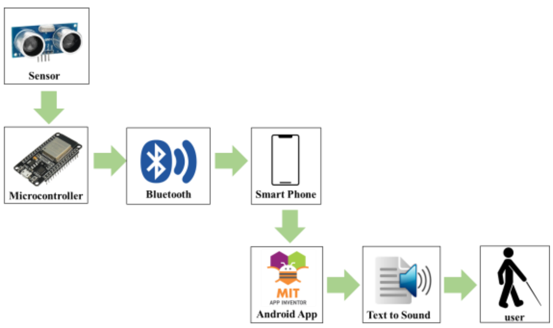


Figure 4. Block diagram of proposed system.

A. Prototype Design and Development

Ultrasonic sensor is a very well-known device with its functionality to measures distance of an object using sound waves. It works by transmitting a sound wave at ultrasonic frequency and waits for it to bounce back from the object. The time delay between transmission of sound and receiving of the sound is used to calculate the distance using the formula of:

$$\text{Distance} = \frac{(\text{Speed of sound} \times \text{time delay})}{2} \tag{1}$$

The HR-SR04 is considered while developing the prototype of the model in this study due to its price, user-friendly interface and functionality. Fig. 5 present the example of HC-SR04. There are four pins on the HC-SR04 which are Vcc (5V supply), Gnd (Ground), Trig (Trigger) and Echo (Receive). The model comes with 5V DC operating voltage and operating current of 15mA. The functionality of the ultrasonic sensor acts as the third eye for the visually impaired people. Close range detection will be done on different sets of obstacle and angle where each of the sensed data will trigger the Virtual Personal Assistant (VPA) which is Google Assistant to notify the visually impaired user.

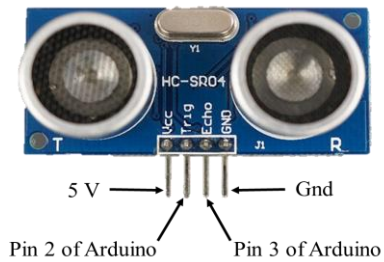


Figure 5. Pins on HC-SR04 ultrasonic sensor.

B. Android Applications Development Using MIT App Inventor

MIT App Inventor is an innovative programming platform for app creation using visual, drag-and-drop building blocks. The simple graphical interface is exceptionally friendly that even an inexperienced novice will be able to create a basic, fully functional app within an hour or less. Fig. 6 illustrated the user interface in which the MIT App is paired with the Bluetooth device while Fig. 7 shows the chain blocks created in programming platform in order to communicate to the Bluetooth module of the ESP32.

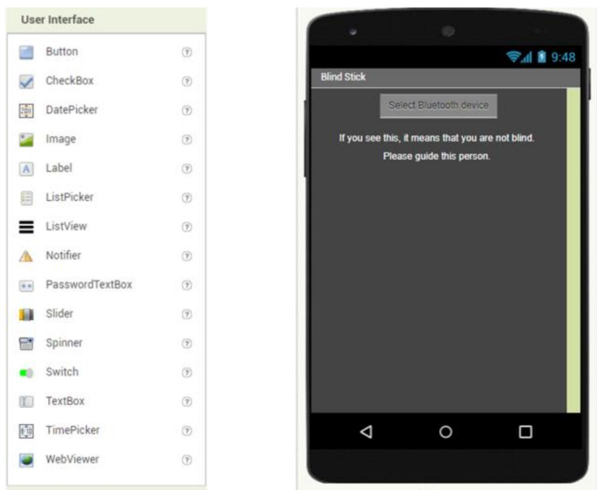


Figure 6. User interface of the Android application shows MIT app inventor designed to scan and pair the Bluetooth device.

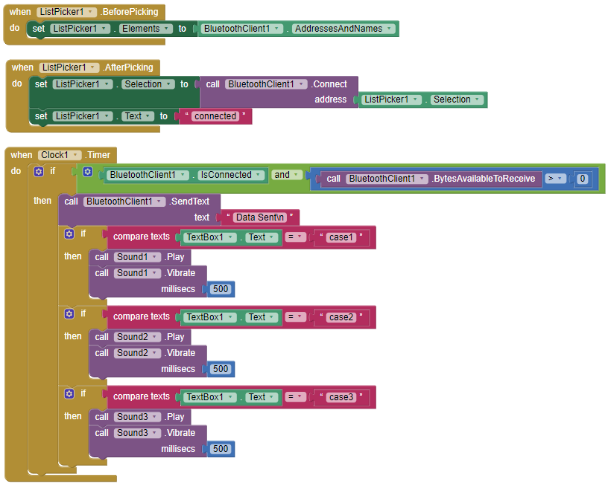


Figure 7. Chain blocks created on MIT app inventor for Bluetooth client service.

C. Operation Mode and Data Documentation

Mounted cane has been a choice for majority of the cane users. The different in the choices made by them is based on the affordability and comfortability. Mounted cane will be used for this project to meet the voice of users. A 3D printed component box will be attached on the mounted cane to equip the component used for prototyping. The process of designing the component box will be done on Adobe TinkerCad and converted into STL file to set the design ready on Cura, a 3D printing software.

24 out of 38, 63.2% of visually impaired person use a white cane with the mounted sensory unit as an assistive tool without requiring any additional device. Only a few considered handheld device (about 28.9%) and kept the computational unit as backpack device on the back of the blind user [17]. In this study, a cane is used as an assistive tool for the visually impaired person instead of standalone handheld and backpack processing unit due to the specific needs of blind users, the targeted operating environment and functionalities.

In this phase, the experimental phase using the final prototype is performed to obtain feedback from the user experience. Coherent to the functionality of sensor used in this project, ultrasonic sensor that has different distance with different angle will be tested in order to acquire the speak output of phone application that can provide navigation for the visually impaired people through this process.

IV. Result and Discussions

The system is tested, and data is tabulated by considering the different positions of the obstacles in order to identify the functionality of the ultrasonic sensor. Actual distance of 250cm, 300cm, 400cm, and 450cm were set to be measured by the ultrasonic sensor. Fig. 8 shows the distance sets on the ultrasonic sensors representing on different obstacle. This distance will be used as the maximum distance to be programmed for the end product. Fig. 9 illustrates the condition of the experiment conducted on the prototype. The prototype is tested when an object is in front of a person and when climbing stairs. Fig. 10 shows example of result obtained from MIT App Inventor for conditional statement if Distance type 1 (stair) and Distance type 2 (object) in which when the value is lesser than 1m, the app will execute "object ahead". The MIT App Inventor in Fig. 10 shows script of history log of obstacle detected for recording purpose.

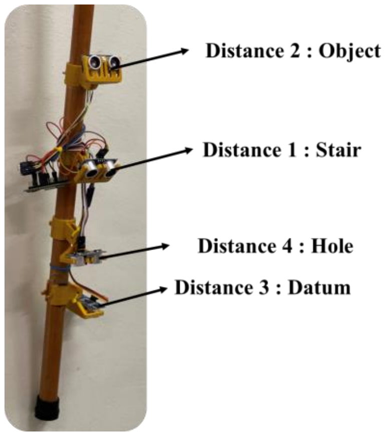
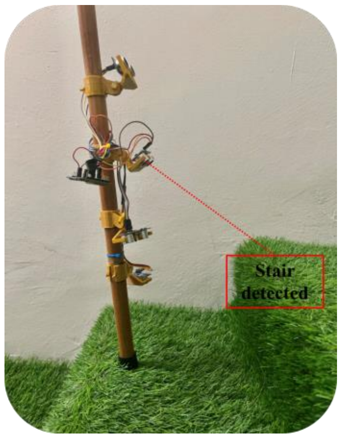


Figure 8. Distance sets on the ultrasonic sensor representing on different obstacle.



a) Closer look when a prototype is used to climb up stairs.

b) Experiment on prototype when an object is in front of a visually impaired person.

Figure 9. Experiment conducted on prototype in different condition.

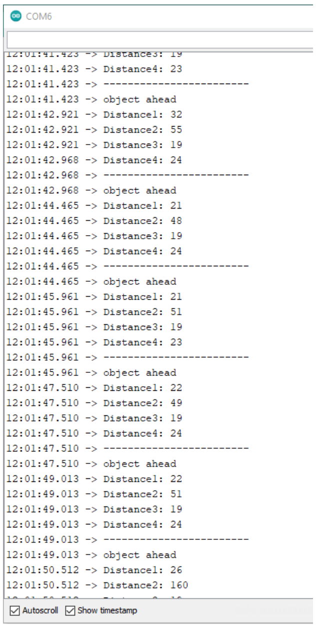


Figure 10. Conditional statement if distance type 1 (stair) and distance type 2 (object) value less than 1m, execute "object ahead".

Table I shows the results on the testing prototype. There are six different measured distance of the obstacle in which the average distance is calculated and difference between the actual and average distance is measured. Based on Table I, it can be clearly seen that the difference between actual and measured distance is slightly smaller. The error percentage of measured distance of 400 cm is higher than the other measured distance as the error detect is slightly higher. In addition, the prototype is tested on different obstacles on angular. The angle detected was in the accuracy range of 30° to 90° during the experimental test conducted. The distance is measured three times until the result achieved is positive in which the result is detected as output on the serial monitor. The obstacle angular location detected is given in Table II.

TABLE I. REAL-TIME DATA COLLECTED FROM THE ULTRASONIC SENSOR

Actual distance (cm)	Measured distance (cm)						Average distance (cm)	Average error (cm)	Error (%)
	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Trial 6			
250	248	252	258	242	253	254	251.16	4.5	0.46
300	289	312	298	289	320	324	305.33	13.33	0.25
350	367	345	356	342	364	332	351.00	11.33	0.30
400	453	437	410	382	432	378	415.33	32.33	3.69
450	438	442	435	447	472	438	445.67	12	0.97

TABLE II. RESULT OF OBSTACLE ANGULAR LOCATION DETECTED FROM THE MEASURED DISTANCE

Measured angle (°)	Output	Result
30	Detected	Accurate
45	Detected	Accurate
60	Detected	Accurate
75	Detected	Accurate
90	Detected	Accurate

V. CONCLUSION

In this paper, an IoT-based obstacle detection system for visually impaired persons with a smartphone module has been successfully developed. The purpose of the developed system is to generate an audio signal to alert the user of the presence of obstacles indoor and outdoor surroundings. The prototype has been tested for detection capability. The results showed that the developed system is able to effectively identify obstacles and water puddles without any faults in its detection range. It accurately detects an obstacle of approximately 99.54% at a distance of 250cm and 99.03% at a distance of 450cm ahead. It is also capable of detecting the angle in the range of 30° to 90°. Additionally, it is able to detect any moving object ahead. The user receives real-time environmental notifications through a mobile app. As a result, it ensures the safety of the user. Hopefully the system will help people with visually impaired persons the independence to live safely, which will ultimately increase their level of confidence in an unfamiliar environment.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Muhammad Farizzul Ilham Mohammad Jalil, Azfarizal Mukhtar, Mohd Ezanee Rusli and Khairul Salleh Mohamed Sahari conducted the research and analyzed the data. Nur Azira Jasman wrote the paper. All authors had approved the final version.

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