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Smart Assistive Cane for the Visually Impaired Using Ultrasonic Sensor and Haptic Feedback

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Abstract

Independent mobility remains one of the most important challenges faced by individuals with visual impairments. Traditional white canes provide essential support for navigation; however, they can only detect obstacles after physical contact, which may limit user awareness and increase the risk of collisions. This study presents the design and development of a smart assistive cane that combines ultrasonic sensing technology with haptic feedback to improve obstacle detection and user safety.

The proposed system consists of an HC-SR04 ultrasonic sensor, an Arduino Nano microcontroller, a vibration motor, a rechargeable lithium-ion battery, and a lightweight cane structure. The ultrasonic sensor continuously measures the distance between the user and surrounding obstacles. When an obstacle is detected within a predefined range, the system activates a vibration motor to provide immediate tactile feedback, allowing the user to react before making physical contact with the object.

To evaluate the effectiveness of the system, experimental testing was conducted with five visually impaired users. A total of twenty navigation trials were performed in both indoor and outdoor environments with obstacles positioned at different distances. The prototype achieved a detection accuracy of 90% and operated continuously for approximately 6.5 hours on a single battery charge. User feedback indicated improved confidence, environmental awareness, and ease of navigation compared with traditional mobility assistance methods.

The results demonstrate that affordable sensing technologies can provide meaningful improvements in accessibility and mobility. Future development may incorporate GPS tracking and Internet of Things (IoT) connectivity to further enhance user safety and real-time location monitoring.

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Introduction

Mobility and environmental awareness are essential for individuals with visual impairments. Safe navigation in public spaces often depends on assistive tools that help users identify obstacles and move independently. The traditional white cane remains one of the most widely used mobility aids because of its simplicity, affordability, and reliability. Despite its effectiveness, the conventional cane requires direct physical contact with obstacles before they can be detected, which may reduce reaction time and increase the likelihood of accidents.

Recent advances in microcontrollers, sensors, and embedded systems have enabled the development of smart assistive technologies that enhance the capabilities of traditional mobility aids. Ultrasonic sensors have become particularly attractive due to their low cost, ease of implementation, and ability to detect obstacles without physical contact. Combined with haptic feedback systems, these sensors can provide immediate tactile warnings that assist users in making safer navigation decisions.

The purpose of this study is to design and evaluate a low-cost smart assistive cane that improves obstacle detection using ultrasonic sensing and vibration-based feedback. The project also serves as an educational demonstration of how accessible engineering technologies can be applied to address real-world challenges.

Literature Review

Smart assistive technologies for visually impaired individuals have received significant attention in recent years. Kuriakose et al. developed an ultrasonic-based smart walking stick capable of improving short-range obstacle detection and enhancing user awareness [1]. Their findings demonstrated the potential of low-cost sensors in mobility assistance applications.

Al-Fuqaha et al. highlighted the growing role of the Internet of Things in enabling communication between smart devices and supporting real-time monitoring applications [2]. Such technologies have the potential to enhance the safety and independence of visually impaired users when integrated into assistive systems. Lee reviewed emerging assistive technologies and emphasized the value of intelligent sensing and connected devices for improving environmental awareness [3]. These developments suggest that future mobility aids may combine obstacle detection, navigation assistance, and location monitoring within a single platform.

Although many existing solutions demonstrate strong performance, some designs require complex hardware or involve higher implementation costs. This project focuses on a simplified and affordable approach while maintaining practical functionality and reliability.

Problem Statement

Visually impaired individuals frequently encounter obstacles that may be difficult to detect using traditional mobility aids alone. Conventional white canes provide tactile information only after contact with an object has occurred. This limitation can affect user safety, particularly in unfamiliar environments.

There is a need for an assistive solution capable of detecting obstacles before physical contact and providing clear warnings that enable users to respond more effectively. Therefore, this project proposes a smart assistive cane that combines ultrasonic sensing and haptic feedback to improve obstacle detection and support safer navigation.

Research Objectives

The objectives of this study are:

1. To design a low-cost smart assistive cane for visually impaired users.
2. To integrate ultrasonic sensing technology for obstacle detection.
3. To develop a haptic feedback mechanism that provides real-time tactile alerts.
4. To evaluate detection accuracy, usability, and battery performance through practical testing.
5. To explore future enhancements involving GPS

tracking and IoT connectivity.

Methodology

System Components

The proposed prototype consists of the following components:

- HC-SR04 ultrasonic sensor
- Arduino Nano microcontroller
- Vibration motor
- 18650 rechargeable lithium-ion battery
- TP4056 charging module
- Lightweight PVC cane structure

System Operation

The ultrasonic sensor continuously emits ultrasonic waves and measures the distance to nearby obstacles. The collected distance information is processed by the Arduino Nano microcontroller. When an obstacle is detected within approximately 80 cm, the vibration motor is activated to provide immediate tactile feedback to the user.

This approach allows obstacle detection without relying on audio signals, making the system suitable for environments where auditory awareness is important.

Testing Procedure

The prototype was evaluated through practical experiments involving five visually impaired users. Testing was conducted in indoor and outdoor environments. Each participant completed navigation trials with obstacles positioned at various distances ranging from 30 cm to 150 cm.

The evaluation focused on:

- Detection accuracy
- Response effectiveness
- Battery endurance
- User comfort and usability

User feedback was collected through structured interviews following the completion of the trials.

Results and Discussion

The experimental results demonstrate that the proposed system can effectively support obstacle detection during navigation tasks.

Parameter	Result
Total Trials	20
Detection Accuracy	90%
Battery Life	6.5 Hours
Estimated Cost	150 SAR

The achieved detection accuracy of 90% indicates reliable performance for short-range obstacle identification. The battery life exceeded six hours of continuous operation, making the device suitable for daily use. In addition, the low estimated cost supports affordability and accessibility for educational and community applications.

Feedback from participants suggested increased confidence during navigation and improved awareness of nearby obstacles compared with conventional cane usage. These observations support the effectiveness of combining ultrasonic sensing with vibration-based feedback.

The findings are generally consistent with previous studies that reported positive outcomes using ultrasonic obstacle detection systems. The results also demonstrate that practical assistive technologies can be developed using affordable and readily available hardware components.

Conclusion

This study presented the design and evaluation of a smart assistive cane that combines ultrasonic sensing and haptic feedback to support obstacle detection for visually impaired individuals. The developed prototype successfully detected obstacles with an accuracy of 90% while maintaining more than six hours of continuous operation on a single battery charge.

The project demonstrates that low-cost electronic components can be integrated into an effective assistive mobility solution that enhances user confidence and environmental awareness. Beyond its practical benefits, the project highlights the potential of STEM-based innovation in developing technologies that address real community needs.

Future work may focus on incorporating GPS tracking capabilities and IoT connectivity to enable real-time location monitoring, emergency support functions, and enhanced user safety [1-4].

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