SafeStep: Smart Blind Stick Using Ultrasonic Sensor and Arduino Uno

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Abstract

Independent mobility remains a significant challenge for visually impaired individuals, who traditionally rely on tactile feedback-based navigation aids such as the white cane. While effective, such tools often fail to detect obstacles beyond ground level or provide early warnings. This paper presents SafeStep, a low-cost smart walking stick designed to enhance situational awareness through non-contact obstacle detection. The system integrates an Arduino Uno microcontroller with an ultrasonic sensor to continuously monitor the environment. A distance-based control algorithm generates graded audio-visual feedback, where alert frequency increases as the user approaches an obstruction. Experimental evaluation of the prototype demonstrates reliable real-time performance with an average error margin below 2%. Owing to its affordability, simplicity, and responsiveness, SafeStep represents an accessible assistive technology solution suitable for deployment in resource-constrained environments. The complete source code is publicly available at https://github.com/nipunsaif/SafeStep.

***K*eywords** Assistive Technology · Smart Walking Stick · Arduino Uno · Ultrasonic Sensor · Visually Impaired

1 Introduction

Visual impairment is a major global health concern, affecting approximately 2.2 billion people worldwide and significantly limiting independent mobility [1]. The conventional white cane remains the most widely used navigation aid; however, its reliance on tactile feedback restricts its ability to detect elevated obstacles or hazards beyond immediate ground contact [2, 3]. Recent advancements in Electronic Travel Aids (ETAs) have introduced sensor-based solutions to address these limitations. Despite their effectiveness, many such systems remain economically inaccessible in developing regions due to high hardware complexity and power requirements [4, 5]. This work proposes SafeStep, a cost-efficient smart walking stick designed to balance functional reliability with affordability.

2 Objectives and Rationale

The primary objective of this project is to design a lightweight, affordable, and reliable assistive navigation device for visually impaired users, emphasizing accessibility in low-resource environments [4]. The specific objectives are:

- To design a non-contact obstacle detection system using ultrasonic sensing.

- To implement a graded proximity-based alert mechanism for intuitive feedback.
- To minimize production cost while maintaining functional reliability.

3 Background Studies

Several studies have explored sensor-assisted navigation aids for visually impaired users. Mahmud *et al.* [2] proposed an ultrasonic sensor-based smart stick capable of distance measurement; however, the system relied on binary alert signals, limiting the user's ability to estimate proximity. Swain *et al.* [6] integrated GPS and GSM modules to enable location tracking and emergency communication, but this significantly increased power consumption and system cost. Similarly, Dhanraj and Kumar [5] demonstrated an embedded-system-based walking aid that improved obstacle detection accuracy but remained financially impractical for widespread adoption. Alternatively, Gayathri *et al.* [4] explored infrared sensor-based solutions to reduce costs; however, their performance degraded under strong ambient lighting. Yadav [3] further highlighted the limitations of IR-based blind sticks in outdoor environments. In contrast, SafeStep prioritizes ultrasonic sensing combined with a software-defined graded alert mechanism to enhance spatial awareness without increasing hardware complexity or cost.

4 Methodology

This section elucidates the system design, detailing both the hardware and the software control algorithms employed.

4.1 System Architecture

The SafeStep system is centered around an Arduino Uno R3 microcontroller. Environmental data is acquired through an HC-SR04 ultrasonic sensor, while user feedback is delivered via a piezo buzzer and an LED. Power is supplied by a 9V battery regulated to 5V using an LM7805 voltage regulator to ensure stable operation.

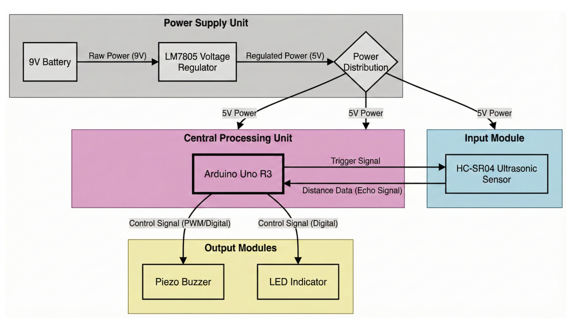

Figure 1: Block diagram of the SafeStep system.

4.2 Circuit Design and Hardware Implementation

The prototype was assembled on a breadboard for modular testing. The ultrasonic sensor interfaces with digital pins 6 (Trigger) and 7 (Echo). The buzzer and LED are connected to digital pins 11 and 12, respectively.

4.3 Control Algorithm

Obstacle distance is computed using the ultrasonic time-of-flight principle, which has been widely adopted in assistive navigation systems due to its reliability and low computational overhead [2, 3]:

$$D = 0.017 \times T \tag{1}$$

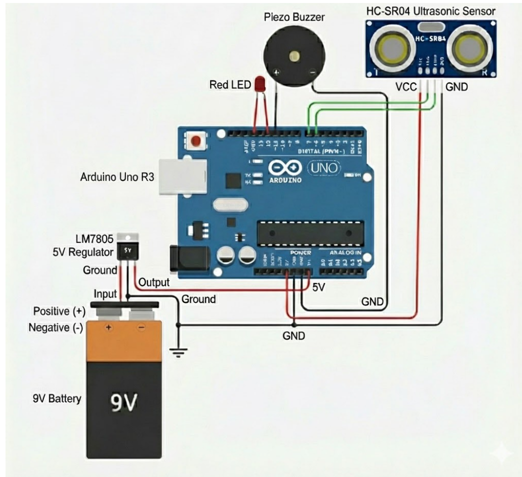

Figure 2: Circuit diagram of the SafeStep system.

where D is the distance in centimeters and T is the echo pulse duration in microseconds. The alert mechanism is divided into three proximity zones:

- **Zone 1 (< 80 cm):** Low-frequency alert (1000 ms interval).
- **Zone 2 (< 50 cm):** Medium-frequency alert (500 ms interval).
- **Zone 3 (< 25 cm):** High-frequency alert (200 ms interval).

5 Results and Discussion

The assembled prototype was mounted on a standard walking cane and evaluated in controlled indoor environments containing static obstacles at varying distances.

5.1 Accuracy Evaluation

Table 1 presents a comparison between actual and measured obstacle distances obtained during experimental testing.

Table 1: System Accuracy and Response

Actual Dist.	Measured Dist.	Error	Response
100 cm	101.2 cm	+1.2%	No Alert
75 cm	75.5 cm	+0.6%	Slow Beep
45 cm	44.8 cm	-0.4%	Medium Beep
20 cm	20.1 cm	+0.5%	Fast Beep

The system demonstrated an average measurement error below 2%, with a processing latency under 100 ms, ensuring timely feedback for normal walking speeds. The low error margin can be attributed to the short operational range and favorable indoor conditions, where obstacle surfaces exhibit high ultrasonic reflectivity and minimal environmental interference. These factors contribute to stable echo detection and consistent time-of-flight measurements. One inherent limitation of the system is the ultrasonic sensor's narrow detection cone, which may result in missed detection of thin, angled, or recessed obstacles. Despite this, the graded alert strategy mitigates sudden user response by providing progressively increasing feedback as obstacles approach. Compared to binary alert-based systems reported in earlier studies [2, 4], the graded feedback mechanism implemented in SafeStep enables users to intuitively estimate obstacle proximity, thereby improving situational awareness and reaction confidence.

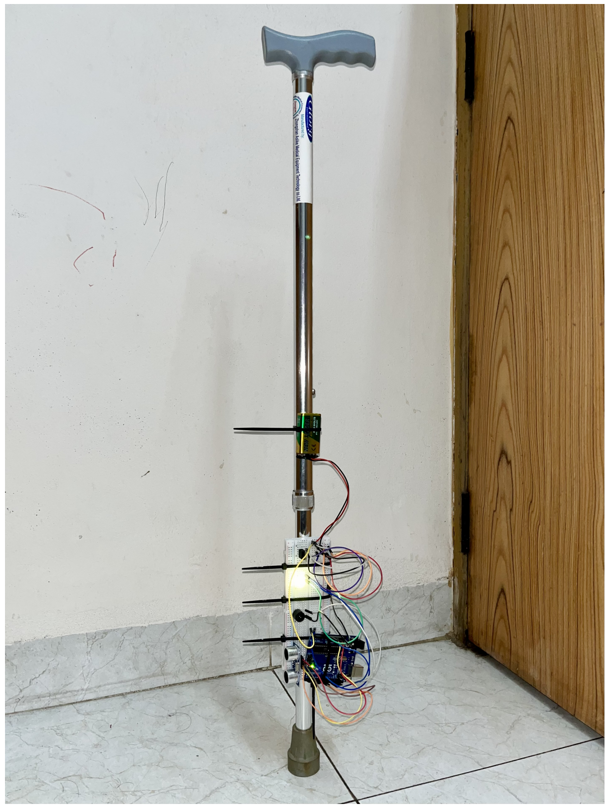

Figure 3: Hardware implementation of the SafeStep prototype.

6 Conclusion

This paper presented SafeStep, a low-cost smart walking stick designed to improve independent mobility for visually impaired users. By combining ultrasonic sensing with a graded alert algorithm, the system provides intuitive, real-time obstacle awareness within an 80 cm range. With a total cost of approximately 1170 BDT, SafeStep offers an economically viable assistive technology solution. Future enhancements will focus on integrating haptic feedback and exploring vision-based obstacle classification.

References

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