

SAFESTEP PROJECT PROPOSAL

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1 Introduction

1.1 Problem and Solution

1.1.1 Problem

White canes provide reliable obstacle detection, but they do not give route-level navigation to help a user reach a destination efficiently. This can make it harder for blind or low-vision users to travel independently in unfamiliar areas. In addition, audio-only directions are not always accessible for users who are deaf or hard of hearing, and if a user falls there is often no automatic way to notify others quickly, which can delay assistance.

1.1.2 Solution

We propose a modular smart attachment that mounts onto a standard white cane to improve navigation and safety without replacing the cane's core purpose [1]. The attachment will connect via Bluetooth to a user's phone and headphones to support clear spoken directions, and it will also provide vibration-based cues for users who need non-audio feedback. The vibration cues will convey information such as turns, continuing straight, and arrival based on a set of vibrations. In addition to navigation support, the attachment will also allow personal safety through fall detection and emergency alert functionality. When a fall is detected the module will send an SMS message to an emergency contact notifying them about the fall and the user's last known location. This allows the user to get assistance quickly in the event of an emergency.

1.2 Objectives and Background

1.2.1 Goals and Benefits

- Offer a modular, low-profile attachment that preserves the simplicity, reliability, and affordability of a standard white cane.
- Support audio and haptic feedback for directions and accommodate users who are deaf or hard of hearing.
- Improve personal safety by detecting falls and notifying an emergency contact and providing the user's last known location.

1.2.2 High-Level Requirements

- The system must be able to provide clear navigation through audio and vibration cues to guide the user towards a destination.
- The system must be able to detect falls and trigger an emergency alert to a pre-set emergency contact and give the user's last known location.
- The system must connect to the user's phone via Bluetooth and headphones to support navigation and emergency alerts.

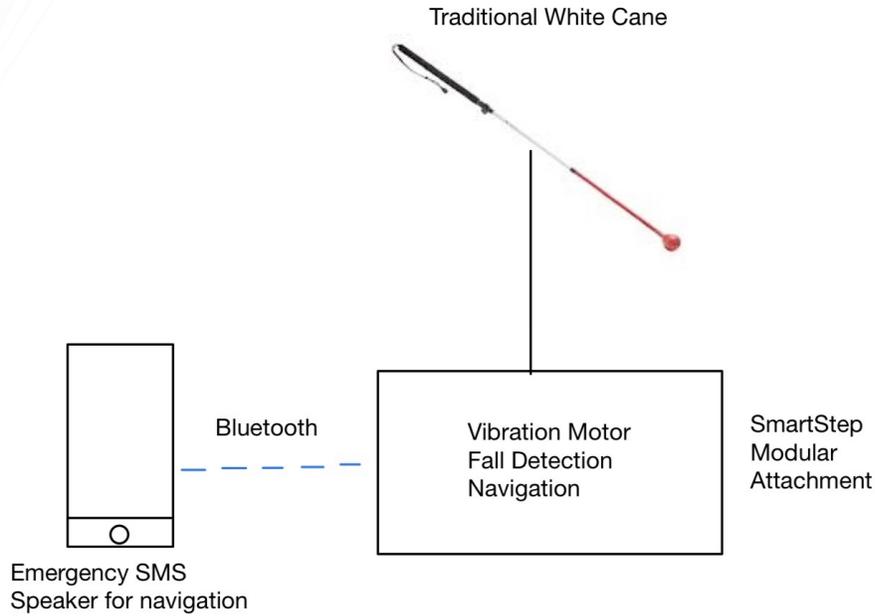


Figure 1: Smart Cane Attachment Visual Aid

1.2.3 Visual Aid

2 Design

2.1 Block Diagram

2.2 Subsystem Overview

2.2.1 Power

This subsystem manages the electrical energy for the entire device, utilizing a USB-C charging module to replenish a LiPo battery. A voltage regulator ensures a stable power supply is distributed to the microcontroller and all peripheral components, protecting sensitive electronics from voltage fluctuations.

2.2.2 Local Sensing

The Local Sensing subsystem gathers real-time environmental data to assist navigation and monitor user safety [2]. It employs a TFmini LiDAR sensor to detect obstacle proximity and an MPU-9250 IMU to track motion and orientation, communicating this data to the central controller via UART and I²C protocols respectively.

2.2.3 Connectivity & Control

Acting as the central processing unit, this subsystem runs on an ESP32 microcontroller that handles logic execution and Bluetooth Low Energy (BLE) communication. It processes inputs from physical interface buttons (Power/SOS, Cancel) and coordinates data flow between sensors, output devices, and the user's smartphone.

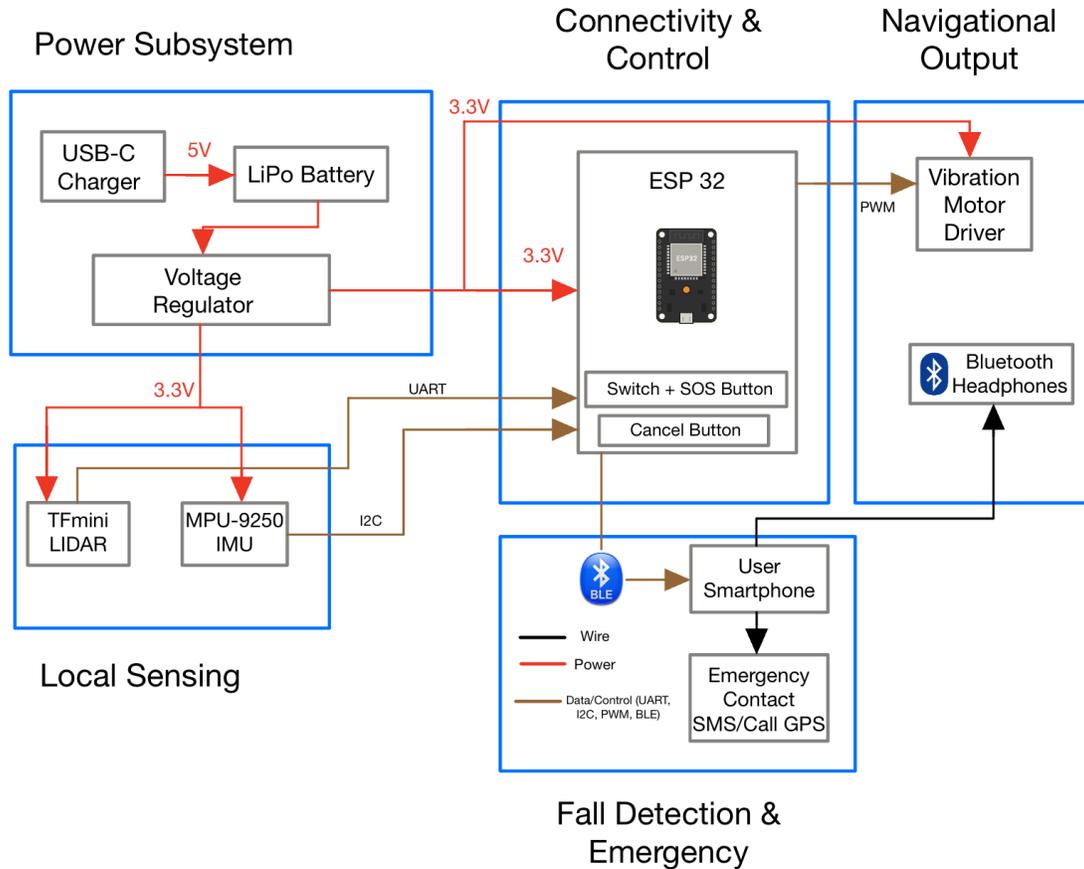


Figure 2: Smart Cane Attachment System Block Diagram

2.2.4 Navigational Output

This subsystem provides feedback to the user through both haptic and audio channels to ensure accessible navigation. A vibration motor driver converts PWM signals into distinct haptic cues, while the system leverages the smartphone’s Bluetooth connection to transmit spoken directions to the user’s headphones.

2.2.5 Fall Detection & Emergency

Designed for critical safety, this subsystem uses IMU data to identify potential fall events and triggers an automated emergency workflow. Upon confirmation of a fall or a manual SOS press, the ESP32 signals the user’s smartphone via BLE to send an SMS or call a pre-set emergency contact with GPS location data.

2.3 Subsystem Requirements

2.3.1 Power (USB-C Charger + LiPo + Voltage Regulator)

The power subsystem stores energy in a rechargeable LiPo battery, supports charging through USB-C, and uses a voltage regulator to provide a stable rail for the ESP32, sensors, and motor

driver. This enables continuous operation and prevents resets during Bluetooth communication and vibration events.

Interfaces

- USB input: 5 V to charging circuitry.
- Battery output: single-cell LiPo to regulator.
- Regulated output: 3.3 V nominal to ESP32, sensors, and driver logic.
- Motor supply provided to the motor driver.

Subsystem must meet

- Provide $3.3\text{ V} \pm 10\%$ to logic components during operation.
- Support average system current of at least 300 mA with tolerance for higher short bursts.
- Enable approximately 1 hour of operation under normal use.
- Safely recharge the battery from a standard USB source.

2.3.2 Connectivity & Control Subsystem (ESP32 + Buttons)

The ESP32 coordinates the device. It maintains BLE communication with the smartphone, receives sensor data, interprets button inputs, executes fall-detection logic, and commands vibration outputs. This supports connectivity, navigation response, and emergency triggering.

Interfaces

- BLE link between ESP32 and smartphone.
- UART from TFmini-S LiDAR.
- I²C from MPU-9250 IMU.
- PWM/GPIO to motor driver.
- Digital inputs from SOS and cancel buttons.

Subsystem must meet

- Maintain BLE connectivity at distances up to about 10 meters indoors.
- Read and process sensor updates at least 10 times per second.
- Respond to button presses within 0.5 seconds.
- Send a trigger to the phone within 5 seconds of detecting a fall or SOS input.

2.3.3 Navigational Output Subsystem (Motor Driver + Vibration Motor + Phone Audio)

This subsystem delivers feedback through vibration cues and spoken directions from the smartphone to Bluetooth headphones. It ensures navigation remains accessible to users with different needs.

Interfaces

- PWM/GPIO from ESP32 to motor driver.
- Power from the power subsystem to the driver and motor.
- Audio from smartphone to Bluetooth headphones.

Subsystem must meet

- Provide at least four distinct vibration patterns.
- Begin vibration within roughly 0.5 seconds of a command.
- Deliver sufficient drive current for noticeable haptic feedback.

2.3.4 Local Sensing Subsystem (TFmini-S LiDAR + MPU-9250 IMU)

The sensing subsystem measures obstacle distance and user motion. The LiDAR provides proximity information, and the IMU supplies acceleration and orientation data used in fall detection.

Interfaces

- TFmini-S to ESP32 via UART.
- MPU-9250 to ESP32 via I²C.
- Powered from regulated rail.

Subsystem must meet

- Detect obstacles from approximately 0.3 m to 8 meters.
- Provide updated measurements at least 10 times per second.
- Provide motion data sufficient to differentiate normal walking from fall events.

2.3.5 Fall Detection & Emergency Subsystem (ESP32 Logic + Phone Automation)

The ESP32 analyzes IMU data to detect potential falls. When a fall is confirmed or the SOS button is pressed, the ESP32 sends a BLE signal to the smartphone, which then contacts an emergency person and shares location information.

Interfaces

- IMU data into ESP32.
- BLE trigger from ESP32 to smartphone.
- Smartphone communication to emergency contact.

Subsystem must meet

- Detect fall-like events within approximately 5 seconds.
- Provide a cancel window of roughly 10 seconds.
- Successfully initiate the phone's emergency message or call after confirmation.

2.4 Tolerance Analysis

One point of failure that could pose a risk to the successful implementation of the project is the system latency in providing alerts, and the effect it has on stopping time. This can be crucial in scenarios such as preventing collisions, notifying the user of crosswalks or other traffic controlling mechanisms, and avoiding dangerous hazards (ditches, streams, inclined platforms).

For this we consider a scenario in which a user is walking at a fast pace, and the LiDAR sensor on the device detects an object that is 2 meters away.

Variables

V_{walk} : walking speed, approximately 1.3 m/s

T_{sys} : system latency, approximately 1.0 s

T_{react} : human reaction time, approximately 0.3 s

T_{mech} : mechanical stop time, time to decelerate to stopping speed, approximately 0.5 s

Total time

$$T_{\text{total}} = T_{\text{sys}} + T_{\text{react}} + T_{\text{mech}} = 1.8 \text{ s}$$

Distance calculations

$$D_{\text{latency+reaction}} = (T_{\text{sys}} + T_{\text{react}}) V_{\text{walk}} = (1.3 \text{ s})(1.3 \text{ m/s}) = 1.69 \text{ m}$$

$$D_{\text{deceleration}} = T_{\text{mech}} V_{\text{walk}} = (0.5 \text{ s})(1.3 \text{ m/s}) = 0.65 \text{ m}$$

$$D_{\text{total}} = 0.65 + 1.69 = 2.015 \text{ m}$$

This analysis shows that 2.015 meters are needed to come to a complete stop, while the object is only 2 meters away, which will likely result in a collision. Strategies such as rerouting or collision avoidance will most likely need to be implemented instead of relying solely on stopping alerts.

3 Ethics and Safety

3.1 Ethical Considerations

The main ethical considerations that must be kept in mind during the course of the project are the following: Public Safety, System Reliability, truthfulness in medical claims, data privacy and security, product testing and consent

3.1.1 Public Safety

In accordance with IEEE I.1[3], which mandates holding the safety, health, and welfare of the public paramount, our design should prioritize user safety above all else. Since visually impaired users will rely on our device to detect obstacles and request help, any failure could lead to physical injury or stranding. We must ensure that the “smart” attachment does not interfere with the cane’s fundamental function as a reliable white cane; if the battery dies or the electronics malfunction, the cane must remain physically usable. Furthermore, reliance on automated phone shortcuts for emergency SOS alerts poses a safety risk if the phone is dead, disconnected, or if the operating system kills the background process. To mitigate this, we must clearly define the device as a secondary aid rather than a primary life-safety tool and design fail-safes that prioritize the user’s immediate physical safety over complex electronic features.

3.1.2 System Reliability

Reliability is critical for a navigation aid, as inconsistent feedback can be more dangerous than no feedback at all. Our use of a single-point LiDAR sensor (TFmini-S) and an IMU (MPU-9250) introduces potential points of failure, such as the inability to detect glass doors, artifacts, or fast-moving objects. If the system produces false negatives, the user could collide with a hazard; conversely, frequent false positives could degrade the usefulness of the device. To address this, we will need to perform rigorous testing of sensor limitations and implement software filtering to help remedy these fault points. We must also ensure the Bluetooth connection is robust, as a dropped connection during navigation instructions could leave a user disoriented in an unfamiliar location.

3.1.3 Truthfulness in Medical Claims

As per IEEE I.3[3], we must be honest and realistic in our claims, avoiding any misrepresentation of our project as a certified medical device. While the system includes “fall detection” and “emergency alerts,” it is not a medical-grade monitor and has not undergone the rigorous validation required by agencies such as the FDA[4]. We must explicitly label the device as a “prototype device” or “assistive technology” rather than a medical safety product. Overstating the accuracy of any medical-related use cases would be deceptive and potentially dangerous, so we should transparently disclose these limitations in all documentation and user interfaces.

3.1.4 Data Privacy and Security

The collection and transmission of location data for the emergency alert system raises significant privacy concerns under IEEE I.1[3]. Our device transmits the user’s last known GPS coordinates via SMS to a pre-set contact. If this data were intercepted or if the device were hacked, a malicious actor could track the movements of a vulnerable user. There is also a possibility that auxiliary data (such as health-related measurements, if ever added) could be intercepted and misused. To adhere to ethical standards regarding user privacy, we should minimize data collection, ensure that communications occur through a secure medium where possible, and ensure that users have full transparency and control over who receives their data and when it is sent.

3.1.5 Product Testing and Consent

Developing assistive technology for people with disabilities requires strict ethical adherence. We recognize that testing the device on ourselves (the engineering team) does not accurately represent the experience of a blind user. However, testing on applicable groups without proper approval and safety oversight is unethical. Therefore, we will restrict our current testing to team members and simulation environments. If we plan to do user trials, we will need to obtain informed consent from participants.

3.2 Safety Considerations

The following safety considerations protect users and the design team from potential bodily harm: electrical and battery safety, mechanical and environmental safety, and laboratory and development safety.

3.2.1 Electrical and Battery Safety

The inclusion of a battery and microcontroller in a handheld device introduces specific electrical hazards. The primary risk is thermal runaway or battery explosion if a battery cell is punctured, overcharged, or short-circuited [5]. Since the device is held directly in the user’s hand for extended periods, even minor overheating could cause discomfort or burns. To mitigate this, we must integrate a battery management system with proper protections [6]. Additionally, the circuitry must be secured in a waterproof casing to prevent any risk of electric shock, particularly if the device is used in wet conditions.

3.2.2 Mechanical and Environmental Safety

Mechanically, the attachment must be robust enough to withstand daily impact, wear, and tear. If the casing cracks, it could expose sharp edges or internal electronics, posing a physical danger to a user who navigates by touch. The design must also be water-resistant (aiming for an appropriate IP rating). Ergonomically, the attachment must not significantly alter the balance or weight of the cane, as this could cause wrist strain and discomfort for the user.

3.2.3 Lab and Development Safety

During the development phase, we will adhere to strict laboratory safety protocols to protect our team. We will follow course-staff guidelines on safe handling of lab equipment and design components. Product testing must be done in a controlled, safe environment, and a standard operating procedure will be established for testing the fall detection system so we do not injure ourselves while simulating falls.

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