SMARTNAV CANE: A Sensor-Integrated Mobility Aid for Enhanced Navigation

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Abstract **— The SmartNav Cane integrates dual-mode obstacle detection and GPS navigation into a portable aid for visually impaired individuals. Time-of-Flight and Infrared sensors provide 0.5–4 m of obstacle detection coverage, while an ESP32 microcontroller fuses data and accesses Google Maps API for turn-by-turn guidance. Audio cues alert users to hazards with ≤ 500 ms latency and voice prompts ≤ 5 m navigation error. Prototype evaluation on a university campus confirmed reliable detection of low/high-level obstacles and accurate navigational routing. SmartNav improves situational awareness over conventional canes without sacrificing affordability or battery life. Future work includes user trials and smartphone app integration.**

Index Terms — Assistive devices, global positioning system, obstacle detection, sensor fusion, visually impaired

I. Introduction

According to the World Health Organization (WHO) statistics, over 2.2 billion people struggle with vision disorders [1]. Visual disorders can be characterized by low acuity or a limited visual field, which presents some issues in daily tasks. This issue results in self-navigation problems in unfamiliar environments. The application of conservative aids, such as canes, is economical but cannot detect obstacles. Alternatively, the use of guide dogs requires extensive financial and training considerations.

Different solutions, such as navigation apps, smart glasses, navigation systems, wearable devices, and smart canes, have been developed to aid people who are visually impaired. The smart cane-based solution offers additional benefits, including enhanced safety, distance measurement, feedback mechanisms, obstacle detection, and both indoor and outdoor navigation. Recently, the development of smart canes has experienced significant enhancement, with the utilization of processing units and sensor technologies to enhance user safety and improve obstacle detection [2].

This improvement allows the vision-impaired individuals to move independently. The use of blind assistance devices such as cameras, ultrasonic sensors, and GPS provides complete obstacle detection. Promising technologies such as Deep Learning (DL), artificial intelligence, and machine learning techniques have also further improved the development of the smart cane.

Numerous researchers have currently introduced the development of a smart cane to help visually impaired individuals. In [3] developed a smart cane using 2 ultrasonic sensors. The device worked well in different conditions, including detecting obstacles through audio signals. The sensors also measured the distance between obstacles, providing enough information for the impaired individual's reaction. The authors also included a mobile app with Bluetooth to enhance the cane's performance. However, this study relied on a conservative technique and did not integrate smart technology into the cane. In [4] designed a smart cane for visually impaired individuals based on artificial intelligence. The study aimed to develop a versatile and cost-effective system that can detect and measure an obstacle's distance. Through a smart cane and wearable glasses, the system was expected to detect heart rate, falls, body temperature and humidity-temperature environments. Using a deep neural network technique, the outcome of the design showed a 92.16% accuracy. [5], also designed a walking stick through a combination of a Raspberry Pi and programmable interface controllers as the main control. The stick consisted of an obstacle detection sensor, GPS and altering features. A vibration was used to alert the visually impaired individual, and its location was recorded using the GPS.

With ultrasonic and infrared sensors, a vibration motor, and a Buzzer [6] designed a smart blind cane system. The system identified different obstacles, especially when navigating indoor stairs. The system used was also developed using GPS and GSM modules for real-time position via a mobile app. The smart cane was able to detect an obstacle within a range of 5 to 150 cm, enhancing barrier detection, affordability and the ability of future reliability and accuracy assessment in real-world situations. [7] also designed a lightweight and energy-efficient smart cane to assist the visually impaired individuals in identifying their environment. The smart cane was equipped with an infrared sensor for barrier detection and a water sensor for identifying moisture or dry surfaces. The cane provides alerts through messages when moist or wet surfaces and obstacles are identified in front of the user. The smart cane was able to detect obstacles within a range of 70 cm radius.

This work, therefore, proposes the design of the SmartNav cane through a combination of advanced engineering principles with current radical technology. The smart cane will boost the mobility of visually impaired people, their independence, and safety. The system will integrate smart features, such as GPS and object detection sensors, while providing real-time data. The system will also be equipped with environmentally friendly rechargeable batteries. The aim of this system is to provide a mobility aid for visually impaired individuals to navigate independently and confidently within the University campuses.

II. System components

The SmartNav cane is best understood in terms of the components that make up the system. This section aims to list the components used and give a brief description of their capabilities.

A. Microcontroller

Central to the SmartNav is the ESP32 microcontroller, which serves as the core processor for managing all device operations. This module integrates a dual-core Tensilica Xtensa LX6 CPU running up to 240 MHz, with 520 KB SRAM, and 4 MB of onboard flash. It also supports 802.11 b/g/n Wi-Fi and Bluetooth 4.2 for wireless connectivity. In terms of peripheral support, it houses 34 programmable GPIO pins, and includes interfaces for SPI, I2S, I2C, and UART [8]. The power management is variable with multiple power modes such as active, light-sleep, deep-sleep and more. In our design, one core handles real-time I²C polling of the Time-of-Flight and infrared distance sensors, while the other manages I²S audio output to drive voice prompts. We leverage the ESP32's dynamic voltage and frequency scaling and multiple sleep modes to extend battery life on a single Li-Ion charge. Its integrated RF front-end built-in antenna, RF balun, low-noise amplifier, and power amplifier ensures reliable campus-wide connectivity to the Google Maps API, and its 34 GPIOs interface with the battery charger, status LEDs, and optional Bluetooth-paired smartphone. Figure 2 illustrates the ESP32's key on-board components.

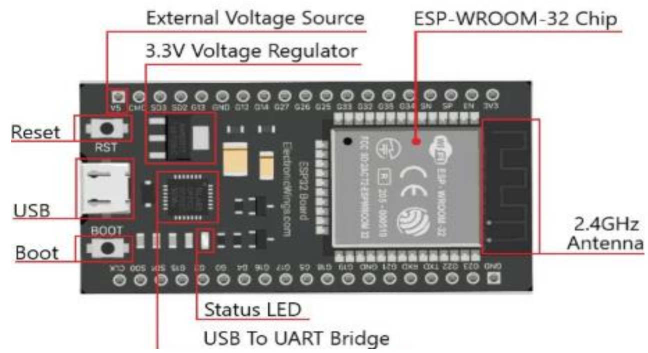


Fig. 2. ESP32 microcontroller board.

B. Object Detection Sensor

For obstacle detection, two sensors were selected to provide a broader application in our system. The STMicroelectronics VL53L1X Time-of-Flight sensor emits a 940 nm laser VCSEL (vertical-cavity surface emitting laser) with a detection range up to 2 m. This sensor provides millimeter level accuracy, with an additional benefit of an adjustable field of view. It allows for easy integration as a single reflowable component using I2C communication and 3.3 V to operate. The Sharp GP2Y0A710K0F Infrared sensor combines PSD (position sensitive detector), IRED (infrared emitting diode), and a signal processing unit to provide a range of up to 5.5 m. It also includes easy integration as an off-the-shelf sensor, requiring 5 V to operate [9].

i.e. infrared and time-of-flight sensors, were applied. An infrared sensor has the capability of detecting obstacles through the emission of infrared light and detecting the reflections from the obstacles, thus enabling the user to identify them. This sensor uses infrared technology to sense changes in the environment or obstacles. The sensors can also sense the proximity, motion and temperature of the surroundings. The IR sensor module is as shown in Figure 3 below

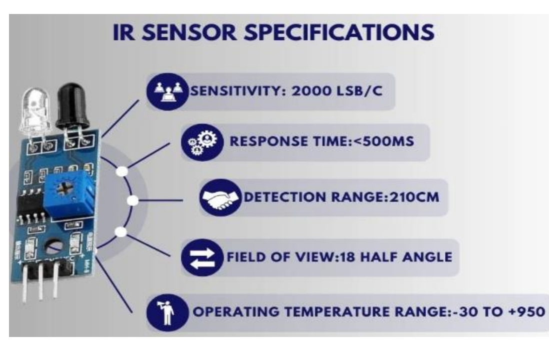


Fig. 3. Infrared Sensor Module

Time-of-flight (ToF) sensors, on the other hand, are ultrasonic sensors for object detection and navigation. These sensors measure the period the signal takes to travel to the obstacle and back. Laser-based ToF cameras are used as scanners which capture the entire scene with laser pulses, as illustrated in Figure 4 below.

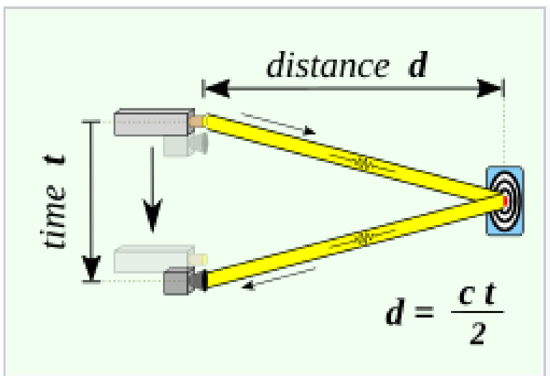


Fig. 4. ToF of the light pulse

C. GNSS Module

The NEO-M9N-00B GNSS is a 92-channel module from u-blox. The NEO-M9N-00B is capable of concurrently receiving 4 GNSS; GPS, GLONASS, Galileo, and BeiDou constellations. This results in higher accuracy in certain places. This module has a 25 Hz max update rate with multi GNSS as well as single GNSS configuration, which will be more than sufficient for the application in which it is being used. This module has an accuracy rating of about 2.0m CEP [10]. Even with such power, this module is relatively low in cost with a compact package, making it ideal for battery operated mobile devices

D. Audio Output Speakers

The audio speakers in a smart cane are used to provide alerts and guidance to the user. For the high-performance of the system, PUI Audio 3W 4Ω Mini Loudspeakers are applied. These speakers operate through an electromechanical driver to produce sound. These speakers are excellent in ensuring an intelligent and reliable sound for the system.

E. Microphone

The Microphones in the smart cane mainly serve as input and voice control units, which enable users to interact with the cane by use of voice commands. For the high performance of the cane, an INMP441digital microphone is used. This microphone is characterized by low power, high performance, and a digital-output port. This microphone also has a high Signal-to-Noise Ratio, making it the best choice for the smart cane, flat, wideband frequency, which leads to high intelligibility of natural sound. The working of the INMP44 microphone is as illustrated in the block diagram below.

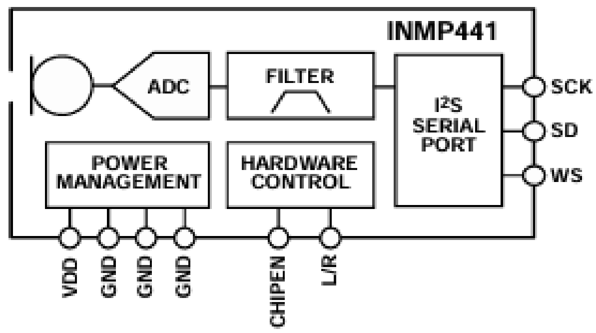


Fig.5. Block diagram of INMP441digital microphone

F. Voltage Regulators

Two voltage regulators were chosen to convert the battery voltage to usable levels by system components. The first was the MIC5365-3.3 linear regulator that offers a stable, low-noise power supply which is crucial to sensitive components. It has a low dropout voltage, high efficiency, and built-in enable pin for flexible management. In addition, its low power consumption and compact package make it ideal for battery-operated mobile devices. The second was the TPS61200 step-up regulator that offers a clean, stable output with robust safety features. It offers exceptional efficiency with a broad input voltage range and adjustable output voltage. With this higher efficiency, the regulator has a low quiescent current and robust load regulation that extends battery life. This also makes it an ideal choice for a battery-operated mobile device. [11], [12]

G. Battery

The 18650 Lithium-ion rechargeable 3.7 V battery is used to power the SmartNav Cane. This battery has a high capacity of 9900 mAh allowing the device to run for long periods of time without needing to be recharged frequently and that coupled with the smaller form factor of 65mm x 18mm and low discharge rate makes this battery an ideal choice for our device.

III. Hardware DESIGN

Following the explanation of system components, this section details the hardware design of the SmartNav cane.

It describes how each component is integrated within the system and used to achieve overall functionality. An early cane sketch has been provided below for the readers' convenience to help visualize the system.

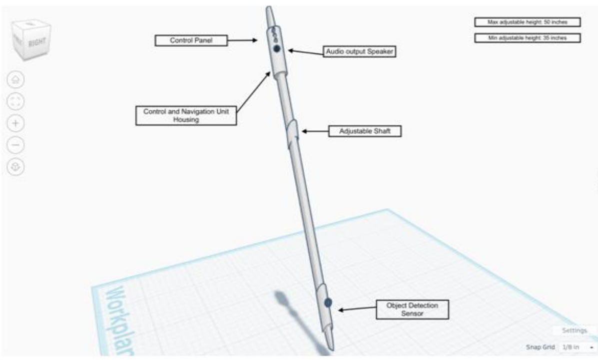


Fig. 6. Early SmartNav cane.

A. GNSS Module

For the system, the NEO-M9N GPS module was applied for the design to offer real-time navigation and location to the user. Alongside the GPS, a backup battery which is used to recall the real-time clock on the satellite orbit, thus reducing the real time for GPS fixing. LED interfaced with the NEO-M9N's TIMEPULSE pin was also included to enable a blinking pattern for the system as a visual cue when a GPS fix has been acquired [13]. This is particularly helpful during troubleshooting of any potential issues.

B. Power Delivery

The power system is considered the critical subsystem for the design of the SmartNav system. The design was based on a 3.7V single Lithium-ion cell, which was precise for adequate energy supply. The boost converter is also used to step up the source voltage from 3.7V to 5V, which is required for most of the system components, including the microcontroller.

C. USB to UART Bridge

The CP2102 USB-to-UART bridge was implemented in the ESP32 Wroom. This component enabled seamless communication between the external and microcontroller systems through the USB system. The system integrates the CP2102 with essential components, such as ESD protection, decoupling capacitors, filters, and diodes to enhance stable and robust serial data transfer. By altering the USB signal to UART, it facilitates debugging and programming of the microcontroller and supports communication during the operation of the system.

D. Button Interface

The button interface is applied in the design to ease the key functions in the system, such as taking audio commands and displaying the battery level. Each of the button interfaces are linked to a microcontroller input and an external resistor to enhance the low logic state when the system is not activated.

E. Sensors

GP2Y0A710K0F Sensor and VL53L0X ToF sensors are used for the design of the smart cane. The VL53L0X ToF module is fixed at the bottom of the system to detect ground-level objects and capture them with its high accuracy and narrow field of view. GP2Y0A710K0F Sensor, on the other hand, is situated at the top of the cane to offer a wider detection range for the detection of distant obstacles.

F. Speaker and Microphone

The NMP441 microphone module and MAX98357A Amplifier were integrated to produce high-quality sound. The NMP441 microphone schematic characteristics enhance easy connections and replacement, thus enabling consistent digital-audio capture via the interface. The MAX98357A Amplifier incorporates vital components like decoupling resistors, capacitors, and filters to enable optimal operation. This integration enables both playback and audio capture to be achieved efficiently, thus enhancing the robust performance of the system.

G. ESP32 Wroom Microcontroller

The ESP32 Wroom Microcontroller is used to act as the CNS of the system by integrating communication interfaces, power management system and peripheral connections. The microcontroller interacts with the USB-to-UART bridge for debugging and programming, and other modules such as the MAX98357 amplifier and INMP441 microphone for audio processing. The overall integration of different components for the design can be summarized using the flow chart in Figure 6 below

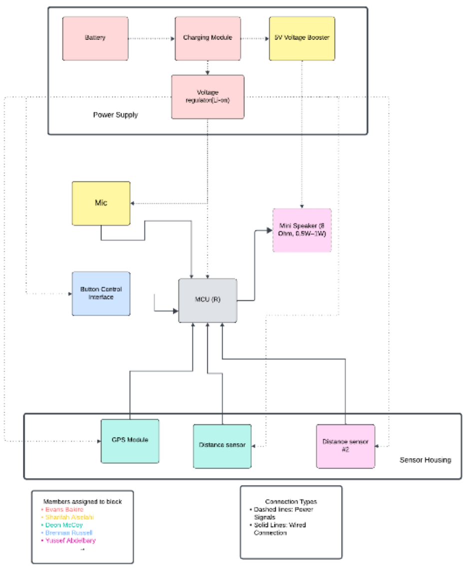


Fig.6. Hardware design Flow chart

IV. SOFTWARE DESIGN

This section acts as the backbone for the design of the system presented. Software architecture highlights the system design and implementation and shows the design of components ranging from data acquisition to navigation processing, object detection, and real-time feedback performance. The logical flow is demonstrated using flow charts and data analysis

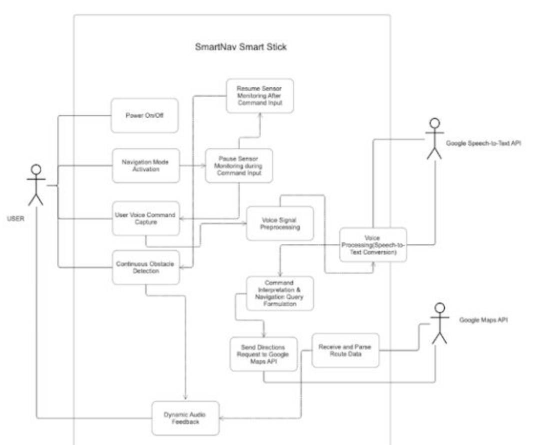


Fig. 7 Use case diagram of SmartNav.

A. Case Diagram

The case diagram for the proposed design of SmartNav cane provides a comprehensive view of different system components and functionalities. At the core of the diagram is the SmartNav user, the primary actor who initiates and interacts with the system through physical inputs such as pressing the navigation button and receiving audio feedback. Surrounding this central role, the diagram delineates critical use cases that form the backbone of the device's operation, including power management (covering functions like power on/off and battery monitoring), navigation mode activation, and voice command capture

B. Navigation API Feedback System.

The SmartNav navigation subsystem combines voice commands with the Google Maps API to offer real-time, turn-by-turn guidance. When the user presses the navigation button, sensor polling is paused to capture and validate a clear voice input if validation fails, the system allows retries before returning to idle. Once approved, the command is converted to text and sent to Google Maps; the returned route is parsed into sequential waypoints. In active guidance mode, GPS readings trigger proximity checks, and reaching each waypoint prompts the next audio instruction. Built-in error handling at every stage ensures a smooth, reliable user experience.

V. Software Detail

With this section it outlines the software architecture, communication protocols, and libraries used in our SmartNav project. The device integrates multiple sensors and modules, requiring real-time data acquisition, processing, and user feedback. Through the use of I2S, I2C, ADC, and UART, the system captures environmental information, voice input, and provides navigation guidance through efficient and responsive firmware running on an ESP32 microcontroller.

A. Audio Input & Output – I2S Communication

The SmartNav walking stick utilizes the I2S (Inter-IC Sound) protocol to manage digital audio communication between the INMP441 microphone and the MAX98357 I2S amplifier. Incoming voice commands are captured via the microphone and transmitted as high-resolution digital data using dedicated I2S lines (data, word select, and clock). The Arduino I2S library is used to configure and manage the audio stream, allowing real-time audio capture.

B. Obstacle Detection – I2C & ADC Integration

Two types of obstacle detection sensors are used in the system: a VL53L1X which is our Time-of Flight (TOF) sensor that is connected via I2C, and a Sharp GP2Y0A710K0F infrared sensor which is connected to an ADC (Analog-to-Digital Converter) pin.

- I2C Communication: The VL53L1X sensor transmits digital distance measurements through the SDA and SCL lines, using the wire.h library for communication. The ESP32 polls this sensor at regular intervals, interpreting measured distances and triggering alerts when obstacles are detected within a certain critical range.

- ADC Readings: The sharp GP2Y0A710K0F outputs a continuous analog voltage correlated to distance. This voltage is read using the analogRead() function on the ESP32's ADC channel. A lookup table and calibration routine maps the voltage to an approximate distance. Filters and signals conditioning are applied to reduce noise, ensuring accurate and consistent detection.

With both sensor they work together to improve environmental awareness, particularly for varying obstacle sizes and distances. When an obstacle is detected, an interrupt or flag-based alert is triggered, sending audio feedback of beep through the speaker.

C. UART Communication and Diagnostics

The SmartNav cane uses UART (Universal Asynchronous Receiver/Transmitter) communication for serial output, diagnostics, and firmware updates. A CP2102N USB-UART bridge connects the ESP32 to a computer or serial monitor, allowing us to monitor live data streams during testing. Using the serial library in the Arduino IDE, sensor readings, and system logs are printed over the UART interface. Although UART is not used for core navigation or audio functions, it plays a crucial role during development and can serve as a fallback channel for system configuration.

D. Task management and Interrupt Handling

To ensure real-time responsiveness, the firmware is structured with a hierarchical task management system. The ESP32 executes tasks either within a timed loop or under freeRTOS, with priority levels based on the function's urgency:

- High Priority: GPS-based navigation updates, voice command parsing, and route recalculation.
- Medium Priority: Obstacle detection using VL53L1X and Sharp sensors, with polling frequencies around 50-100 ms.
- Low Priority: Battery monitoring, diagnostics, and background status checks.

Interrupt Service Routines (ISRs) are implemented for critical user interactions, such as a navigation button press, which immediately halts background processes and activates a new system state. ISRs are lightweight, which are typically setting flags or triggering events that are handled in the main task scheduler. To ensure concurrency, specific high-priority tasks are pinned to specific ESP32 cores using xTaskCreatePinnedToCore().

E. Cloud-Based API integration

The SmartNav Cane enhances its functionality through API integration, primarily with Google Speech-to-text and Google Maps:

- Speech-to-Text API: Captured audio from the user is processed locally and transmitted to Google's cloud API using an HTTPS request. The resulting text is used to identify commands such as "directions to [location]."

- Maps API: The transcription result is converted into a geolocation query, which is sent to Google Maps API. In response, the system receives route data, waypoints, and walking directions in a JSON format.

All HTTP requests are managed using the HTTPClient library. API keys and sensitive data are securely stored and authenticated. Network communication is performed asynchronously, allowing sensor polling and other time-critical tasks to run uninterrupted. With this in place we also have error-handling strategies in place such as retries, fallbacks, and timeout thresholds to ensure continued operation even during intermittent internet connectivity. JSON parsing and decision logic extract relevant information and convert it into structured voice prompts for the user.

F. Waypoint Proximity Monitoring

On the software side, after parsing the Google Maps JSON into an ordered list of latitude/longitude waypoints, the navigation task polls the ESP32's GPS fix at regular intervals under FreeRTOS. At each interval, the Haversine formula computes the great-circle distance to the next waypoint. Once that distance falls below the configurable proximity threshold the system automatically advances to the next waypoint: the pre-synthesized TTS prompt for that step plays immediately, and synthesis of the following instruction proceeds concurrently in the background. By distributing geospatial calculations, audio playback, and background synthesis across dedicated FreeRTOS tasks often pinned to separate cores deterministic timing and seamless, low-latency turn-by-turn guidance are maintained even during continuous movement.

Haversine Distance

- $d = 2r\ arcsine(\sqrt{sin^2\left(\frac{\varphi_2-\varphi_1}{2}\right) + cos\varphi_1 . cos\varphi_2 . sin^2(\frac{\omega_2-\omega_1}{2})})$
- Where
  - φ_1, φ_2 are the latitude of point 1 and point 2 in radian form.
  - ω_1, ω_2 are the longitude of point 1 and point 2 in radian form.

Fig.8. Comprehensive Mathematical Expression of the Haversine Formula between Two Geographic Coordinates

Where R is Earth's radius (≈ 6 371 000 m). Multiplying the central angle (in radians) by the radius gives the arc length along the sphere's surface that is, the great-circle distance between the points.

VI. Physical Board Designs

The Design of the SmartNav Cane's electrical system required a compact and efficient layout to support various components including sensors, a GPS module, an amplifier, voltage regulators, and the ESP32 microcontroller. To achieve this, we designed custom PCBs using Fusion 360, allowing us to consolidate the system's power delivery and sensor integration. During the design process, we encountered challenges sourcing compatible library components for certain modules such as the MAX98357 I2S amplifier, Neo-M9N GPS, and Sharp GP2Y0A710K0F distance sensor. In order to resolve this, we had to import verified footprints based on what we needed. We also ensured that components matched exact pinouts and dimensions through cross-checking data sheets. Power distribution required careful attention, especially due to the inclusion of both 3.3 V and 2.8V regulators, necessary for different sensor operating voltages. Particular care was taken with signal routing for I2C and ADC lines to avoid interference, and ground planes were added to reduce electrical noise. After multiple iterations and Design Rule Checks (DRC), the final PCB met both our mechanical constraints as well as our electrical requirements.

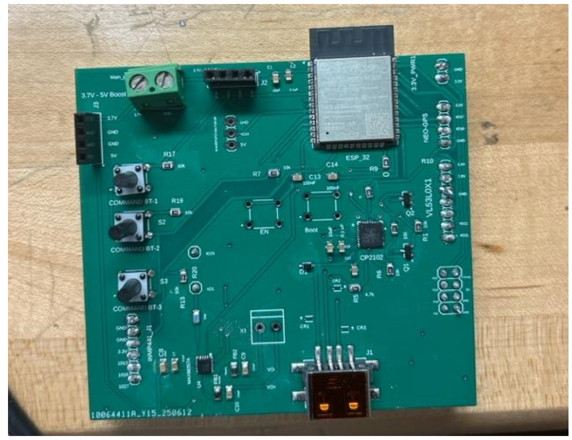


Fig.9. Main PCB Board

Our SmartNav main PCB serves as the device's backbone, centering around the bare ESP32-WROOM module and uniting all essential subsystems onto a single board. It includes an audio amplifier for reliable voice feedback, a UART-to-USB bridge to simplify debugging and data exchange, and a robust power network with voltage regulators and DC-DC converters female pin headers that ensure rock-solid operation. Modular pin headers give us the flexibility to add future sensors and custom breakout boards without redesigning, while the unified layout enhances signal integrity and streamlines troubleshooting. Critical PCB design practices controlled-impedance antenna routing, strict antenna keep-out zones, strategic thermal vias for heat dissipation, and meticulous power-plane management were applied to maximize wireless performance, maintain stable power delivery, and meet electromagnetic-compatibility standards. This holistic approach results in a compact, high-reliability core for the SmartNav system.

Fig.10. GPS Module PCB Board

The GPS receiver sits on its own PCB tethered to the main board this lets us position the antenna in a clear, low-interference spot for stronger satellite reception. We based our schematics and layouts on component datasheets and proven designs of SparkFun and the GY-GPS6MV2. We used Eagle for the electrical drawings and Fusion 360 for board placement and routing. By delegating power regulation, battery charging, and EEPROM management to the main PCB, the GPS breakout remains streamlined, hosting only its receiver circuitry and antenna interface. An onboard backup battery and EEPROM preserve critical ephemeris and location data when power is lost, enabling rapid “hot” or “warm” starts and much faster satellite fixes than a cold start would allow.

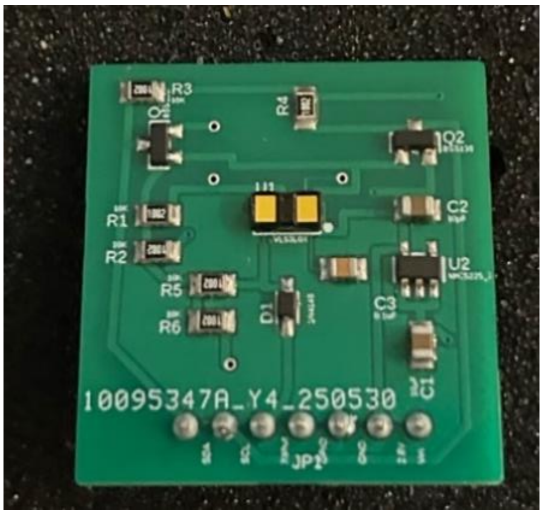


Figure.11. TOF VL531X BreakOut Board

Our smartNav mobility stick incorporates a custom VL53L0X Time-of-Flight breakout board to deliver reliable, real-time distance sensing up to two meters regardless of surface reflectance.

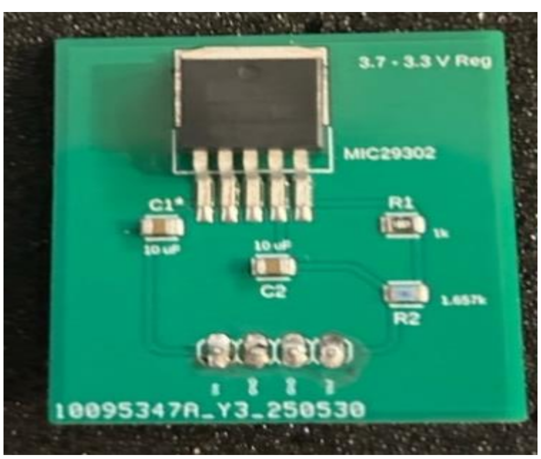


Figure.12. MIS29302-3.3 Voltage Regulator Board

Our MIS29302-based 3.3 V regulator board, which provides a stable, low-noise power rail for the ESP32 module and all downstream sensor circuits. We selected the MIS29302 for its high efficiency, low quiescent current, and built-in thermal protection, enabling reliable operation under variable load.

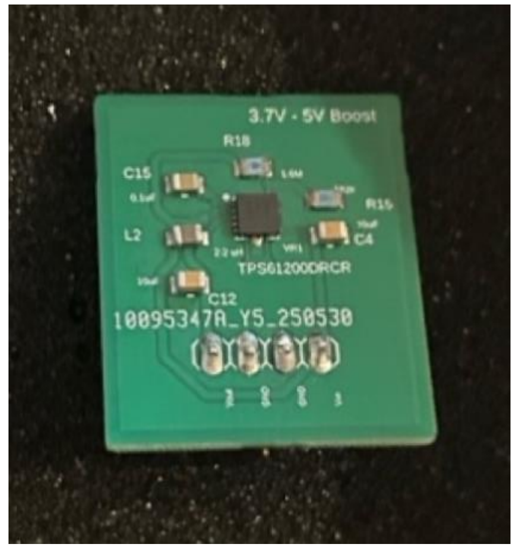


Figure.13. TPS61200 Step-Up Voltage Regulator Board

The TPS61200 boost regulator board, which efficiently steps a single-cell Li-ion battery up to the device’s 5 V rail for peripherals and audio amplification. We chose the TI TPS61200 for its high conversion efficiency across light and heavy loads, integrated power MOSFETs, and adjustable output via a simple feedback network.

VII. Conclusion

Our SmartNav Cane is a technologically enhanced mobility aid designed to assist blind and visually impaired individuals with safer, more confident navigation. By integrating a suite of sensors-including infrared and time-of-flight distance sensors, GPS, Audio feedback systems, and cloud-based APIs-the cane delivers real-time obstacle warning and audio navigation cues. The system was developed with accessibility, modularity, and user-friendliness in mind while also proving to be cost-effective and an adaptable tool for users who rely heavily on environmental awareness. This project not only addressed the engineering challenges of real-time sensor fusion, embedded software design, and hardware integration, but also emphasized human-centered design in the assistive technology space.

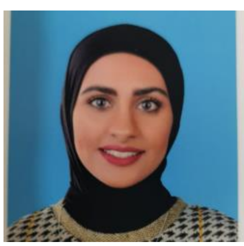
Meet The Team

Evans Bakire is a graduating Computer Engineering student who is passionate about embedded systems and hopes to further his education and pursue a master's degree here at UCF.

Yussef Abdelbary is a graduating Computer Engineering student with a strong interest in embedded systems and assistive technology. He hopes to continue learning so he can contribute his skills to help advance this field of study.

Brennan Russell is a graduating Electrical Engineering student who focuses on power regulation. He is interested in renewable energy systems and plans to continue exploring hardware reliability.

Deon Mccoy is a graduating Electrical Engineering student with a focus on circuit design and sensor integration. He plans to work in electronics design and testing after graduating.



Sharifah Alselahi is a graduating Computer Engineer student who focused on system integration and real-time sensor communication. She plans to further utilize her skills to solve real-world challenges and make an impact on the world of technology.

References

[1] Farooq, Shafi,Khan, Díez, Breñosa, Espinosa and Ashraf, "IoT enabled intelligent stick for visually impaired people for obstacle recognition.," Sensors, vol. 22, no. 22, p. 8914, 2022.

[2] Bastaki,Sobuh, Suhaiban and Almajali, "Design and implementation of a vision stick with outdoor/indoor guiding systems and smart detection and emergency features," Advances in Science and Engineering Technology International Conferences (ASET) , pp. 1-4, 2020.

[3] Panazan and Dulf, "Intelligent cane for assisting the visually impaired," Technologies, vol. 6, no. 12, p. 75, 2024.

[4] Li, Xie and Chen, "An AIoT-based assistance system for visually impaired people," Electronics, vol. 18, no. 12, p. 3760, 2023.

[5] Sahoo,Lin and Chang, "Design and implementation of a walking stick aid for visually challenged people.," Sensors, vol. 1, no. 19, p. 130, 2019.

[6] Nguyen, Duong, Vu,Dinh and Ngo, "Smart blind stick for visually impaired people. In 8th International Conference on the Development of Biomedical Engineering in Vietnam: Proceedings of BME 8, 2020, Vietnam: Healthcare Technology for Smart City in Low-and Middle-Income Countries," Springer International Publishing, pp. 145-165, 2022.

[7] Senthilnathan, Palanivel and Sowmiya, "Intelligent stick for visually impaired persons," In AIP Conference Proceedings, vol. 1, p. 2764, 2023.

[8] ESP-WROOM-32, et al. ESP32 Module. 25 Feb. 2020, dl.espressif.com/dl/schematics/esp32_devkitc_v4_sch.pdf.

[9] "VL53L0X - STMicroelectronics." STMicroelectronics, www.st.com/en/imaging-and-photonics solutions/vl53l0x.html.

[10] u-blox AG. (2023, March 27). NEO-M9N-00B - Standard precision GNSS module: Data Sheet (Rev. R07, Document No. UBX-19014285). Retrieved from https://www.u-blox.com

[11] Texas Instruments, TPS61200 High-Efficiency Step-Up Converter Datasheet, Rev. G, Aug. 2015. [Online]. Available: https://www.ti.com/lit/ds/symlink/tps61200.pdf

[12] Microchip Technology Inc., MIC5365/6 High-Performance Single 150mA LDO, Datasheet DS20006605A, July 2013 [Revised 2021]. [Online]. Available: https://ww1.microchip.com/downloads/en/DeviceDoc/mic5365.pdf

[13] u-blox AG. NEO-M9N: Standard Precision GNSS Module – Integration Manual. Rev. R09, 9 Feb. 2024, Document No. UBX-19014286. u-blox, https://www.u-blox.com.