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Path Finder

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Abstract: Path Finder is a supportive navigation system created to help visually impaired individuals move more safely and confidently. Traditional tools, like white canes, often miss important details especially small obstacles on the ground or hazards at head level. This can lead to accidents and make navigating busy or unfamiliar places stressful. Path Finder addresses these challenges by using smart sensors and wireless communication to give users real-time awareness of their surroundings. The system is made up of two parts, Smart Footwear and Smart Eyewear. The Smart Footwear uses a VL53L0X Time-of-Flight sensor and an ESP32 microcontroller to detect steps, curbs, or uneven ground and send this information wirelessly. The Smart Eyewear, built with an ESP32-C3, warns the user about obstacles at head height. A small buzzer provides simple feedback the closer the obstacle, the faster or louder the sound. By working together, these two devices offer a practical, affordable solution that helps visually impaired users navigate more safely and independently.

I. INTRODUCTION

Path Finder is an innovative Electronic Travel Aid (ETA) developed to improve independent mobility for people with visual impairments. While traditional tools like the white cane are widely used, they have certain limitations. They often fail to detect small changes in ground elevation, such as curbs or potholes, and require constant manual effort, which can be tiring and mentally demanding over long periods. Path Finder addresses these challenges by offering a smarter, technology-assisted approach to navigation.

The system is built around a dual-module design consisting of Smart Footwear and Smart Eyewear that work together seamlessly. The Smart Footwear acts as the primary sensing unit. It uses a VL53L0X Time-of-Flight (ToF) sensor, controlled by an ESP32 microcontroller, to measure distances using infrared laser pulses. Compared to conventional ultrasonic sensors, ToF technology delivers much higher accuracy, enabling the system to reliably detect hazards such as stairs, uneven surfaces, curbs, and potholes before the user steps into danger.

For user comfort and convenience, Path Finder communicates wirelessly using Bluetooth Low Energy (BLE). Distance data collected by the footwear is transmitted to the Smart Eyewear, which is powered by an ESP32-C3 microcontroller. This wireless design removes the need for physical cables running along the body, making the system lightweight and unobtrusive for everyday use.

The Smart Eyewear functions as the feedback centre of the system. It processes the received data and alerts the user through a variable-frequency buzzer. The feedback is intuitive: as the user approaches an obstacle, the buzzer's beeping becomes faster, providing a clear sense of distance without requiring visual input or hand movement. This hands-free auditory guidance helps users remain aware of their surroundings in real time. By combining precise laser-based distance sensing with low-power wireless communication, Path Finder delivers a practical, affordable, and user-friendly solution. The system enhances safety, confidence, and independence, allowing visually impaired individuals to navigate complex environments more comfortably and with greater assurance.

II. SYSTEM CONFIGURATION

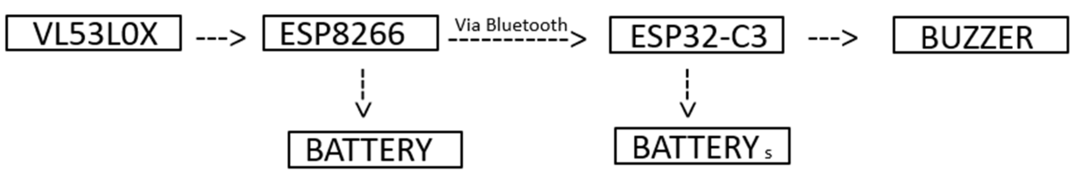

Fig.1.Block diagram of the system

The system is divided into two primary modules: one is High-Precision Distance Sensing (VL53L0X):-At the heart of the system is the VL53L0X Time-of-Flight (ToF) distance sensor. Unlike conventional ultrasonic sensors that depend on sound waves and can be affected by noise, wind, or surface shape, this sensor uses an invisible 940 nm laser to measure distance by calculating how long light takes to reflect back from an object. Because of this technology, the sensor delivers highly accurate distance measurements, even when objects have different colors or surface textures. When placed in the footwear, it becomes especially effective at detecting ground-level hazards such as curbs, steps, potholes, or sudden drops—obstacles that are often missed by traditional aids but can cause serious falls.

Then the second one is Wireless Coordination and Smart Processing: -To keep the system lightweight, flexible, and safe, Path Finder uses two dedicated microcontrollers that share responsibilities wirelessly. This approach is similar to advanced electronic systems where different control units handle specific tasks for better efficiency. Sensing Hub (Smart Shoes):An ESP32 microcontroller processes the distance data collected from the VL53L0X sensor. It filters and analyzes the information to identify nearby hazards that require immediate attention. Feedback Hub (Smart Glasses):An ESP32-C3 microcontroller acts as the communication and feedback controller. It receives processed data from the shoes using Bluetooth Low Energy (BLE), removing the need for physical wires that could interfere with walking. The BLE connection ensures extremely low delay, so warnings reach the user almost instantly—before they take their next step.

III. DESIGN OF THE SYSTEM

Component	Specification
Sensing Technology	VL53L0X (Laser Ranging)
Microcontrollers	ESP32 & ESP32-C3
Communication	Bluetooth Low Energy (BLE)
Power Source	Portable DC Battery
Output Type	Variable-Frequency Auditory Alert

The VL53L0X is a compact, Time-of-Flight (ToF) laser ranging sensor from STMicroelectronics that accurately measures absolute distances up to 2 meters, making it popular in robotics, IoT, and mobile devices for applications like obstacle detection, autofocus, and gesture recognition, offering superior performance over traditional IR sensors by measuring light travel time rather than reflected light intensity**.** Time-of-Flight (ToF) Technology: Emits a laser pulse and measures the time it takes to bounce back, providing precise distance readings independent of target color or reflectivity. Compact Size**:** Integrated into a small package, making it ideal for space-constrained projects.Eye-Safe Laser**:** Uses a 940nm VCSEL laser (Vertical-Cavity Surface-Emitting Laser) that's invisible and safe for human eyes. High Accuracy & Speed**:** Delivers accurate distance measurements with fast performance, even in challenging ambient light Easy Integration**:** Features an I2C interface for simple control and data transfer with microcontrollers like Arduino or ESP32.

The ESP32 is a powerful, low-cost System-on-a-Chip (SoC) microcontroller from Espressif Systems, known for its integrated Wi-Fi and Bluetooth connectivity, making it ideal for Internet of Things (IoT) projects and prototypes requiring wireless communication, featuring a dual-core processor, substantial RAM, and various peripherals like ADC, I2C, and SPI, programmable with environments like Arduino IDE, MicroPython, and Espressif IDF. Processing Power: Includes a Tensilica Xtensa dual-core (or single-core) 32-bit LX6/LX7 microprocessor, clocked up to 240 MHz, offering fast data processing.Wireless Connectivity: Built-in 802.11b/g/n Wi-Fi and Bluetooth (Classic & BLE), eliminating the need for external modules.Memory**:** Comes with significant on-chip SRAM (e.g., 520 KB) and ROM, plus support for external flash.Peripherals**:** Rich set of I/O, including ADC, DAC, SPI, I2C, UART, capacitive touch sensors, PWM, and more, for extensive hardware interfacing.Low Power**:** Designed for energy efficiency, suitable for battery-powered applications.Development Friendly**:** Supports multiple programming environments (Arduino IDE, MicroPython, ESP-IDF) and offers readily available development boards.

The ESP32-C3 is a low-power, cost-effective microcontroller from Espressif Systems, featuring a single-core 32-bit RISC-V processor, integrated Wi-Fi (802.11b/g/n) and Bluetooth 5 (LE) connectivity, and robust security features like secure boot and flash encryption, making it ideal for secure, simple IoT devices, smart home gadgets, and wearables. It offers rich peripherals (GPIO, ADC, I2C, SPI) and supports popular development environments like Arduino IDE and ESP-IDF, balancing performance, power, I/O, and security for connected applications. Processor: 32-bit RISC-V single-core CPU, up to 160 MHz.Connectivity: 2.4 GHz Wi-

Fi and Bluetooth 5 (LE).Security: Secure Boot, Flash Encryption, Digital Signature peripheral, HMAC.Memory: Onboard SRAM and Flash (often 4MB).Peripherals: 22 GPIOs, UART, I2C, SPI, ADC, PWM, I2S, USB Serial/JTAG.Power: Low-power modes, suitable for battery-operated devices.Development: Compatible with Arduino IDE, ESP-IDF. It is a simple electronic component used to produce sounds, beeps, or melodies for alerts, alarms, or feedback in projects, connecting to ESP32 GPIO pins to generate tones by sending voltage signals, often using PWM for different frequencies, and can be either active (self-oscillating) or passive (requires external signal). They're used in everything from doorbells to interactive games, controlled via Arduino IDE functions like ledcWriteTone() or manual GPIO toggling.

A Li-polymer (Lithium Polymer) battery is a rechargeable battery that uses a solid or gel-like polymer electrolyte instead of the liquid electrolyte in traditional lithium-ion (Li-ion) batteries, allowing for a thinner, lighter, and more flexible design. These batteries offer high energy density, are customizable in shape, and are widely used in portable electronics like smartphones, drones, tablets, and RC vehicles, but require careful handling to avoid fire hazards from overcharging or damage. Electrolyte: Uses a polymer electrolyte (solid or gel) for ion transfer, unlike liquid electrolytes in standard Li-ion batteries. Design Flexibility: Can be manufactured in thin, flexible pouches, enabling various shapes and sizes for compact devices.Lightweight & High Energy: Offers a high specific energy, meaning more power in a lighter package, crucial for portability.High Power Output: Capable of delivering high discharge currents, making them ideal for high-demand applications like drones.

IV. PERFORMANCE ANALYSIS OF THE SYSTEM

Path Finder is designed to communicate in a simple and intuitive way, minimizing mental effort for the user. Instead of displaying complex information, the system converts distance data into sound patterns using a buzzer. As the user moves closer to an obstacle, the sound changes automatically:Safe Zone (Above 80 cm): No sound, allowing relaxed and confident movement.Caution Zone (30 cm – 80 cm): Slow, rhythmic beeps that gradually speed up as the obstacle gets closer.Danger Zone (Below 30 cm): A continuous, high-frequency sound that signals an immediate risk, such as a step or drop-off.

The Path Finder system works like a quiet companion that constantly watches the path ahead and gently warns the user whenever something unsafe is detected. It does this through two main steps: detecting obstacles and alerting the user. Detection Mode: In this mode, the sensor in the footwear continuously scans the ground in front of the user. It sends out an invisible beam of light and waits for it to bounce back. By measuring how long this light takes to return, the system can accurately determine how far away an object . Because the sensor is positioned near the feet, it is very good at noticing small but dangerous changes in the walking surface, such as steps, curbs, potholes, or sudden drops. This happens automatically and repeatedly as the user walks, without requiring any effort or attention from them.

Alert Mode: Once the distance is measured, the system decides whether the situation is safe or risky. If there is nothing close by, the system stays silent so the user can walk confidently and without distraction. When an object comes within a moderate distance, the system begins to beep slowly, gently warning the user that something is ahead. As the user moves closer, the beeping becomes faster. If the object is very close and poses an immediate danger, the sound changes into a continuous tone, clearly telling the user to stop or change direction.This gradual change in sound makes it easy for the user to understand how close the obstacle is, without needing to think or analyze the situation.Pathfinder continuously detects, transmits, and provides real-time auditory feedback to create a safety zone around the user. Smart Footwear uses a VL53L0X ToF sensor and ESP32 to measure ground-level obstacles with high accuracy. Distance data is sent wirelessly via Bluetooth Low Energy to the Smart Eyewear. The ESP32-C3 in the eyewear activates a variable-frequency buzzer, where faster beeps indicate closer obstacles, helping prevent falls and collisions.

V. CONCLUSION

The development of the PathFinder system shows how modern sensing and wireless technologies can come together to meaningfully improve independent mobility for people with visual impairments. Instead of relying on conventional tools that have clear limitations, PathFinder uses advanced VL53L0X Time-of-Flight (ToF) sensing to detect ground-level hazards and elevation changes with high accuracy. This allows the system to identify steps, curbs, and uneven surfaces far more reliably than traditional ultrasonic solutions. The project successfully met its key technical goals. The smart footwear module precisely detects potential tripping hazards, delivering consistent performance regardless of environmental noise, lighting conditions, or surface color. By using Bluetooth Low Energy (BLE) communication between the shoe-mounted ESP32 and the eyewear-mounted ESP32-C3, the system removes the need for physical wires, resulting in a safer, lighter, and more comfortable user experience. Distance information is conveyed through a variable-frequency buzzer, transforming complex sensor data into clear, real-time audio cues that are easy for users to understand and respond to.

Although the current prototype primarily focuses on ground-level safety, it stands as a strong proof-of-concept for a distributed wearable assistance system. Its modular design opens the door to future enhancements, such as head-level obstacle detection, vibration-based haptic alerts, or expanded sensor coverage. Overall, PathFinder demonstrates that affordable, off-the-shelf components can be thoughtfully combined to create impactful assistive technology—empowering visually impaired individuals with greater confidence, safety, and independence in their daily lives.

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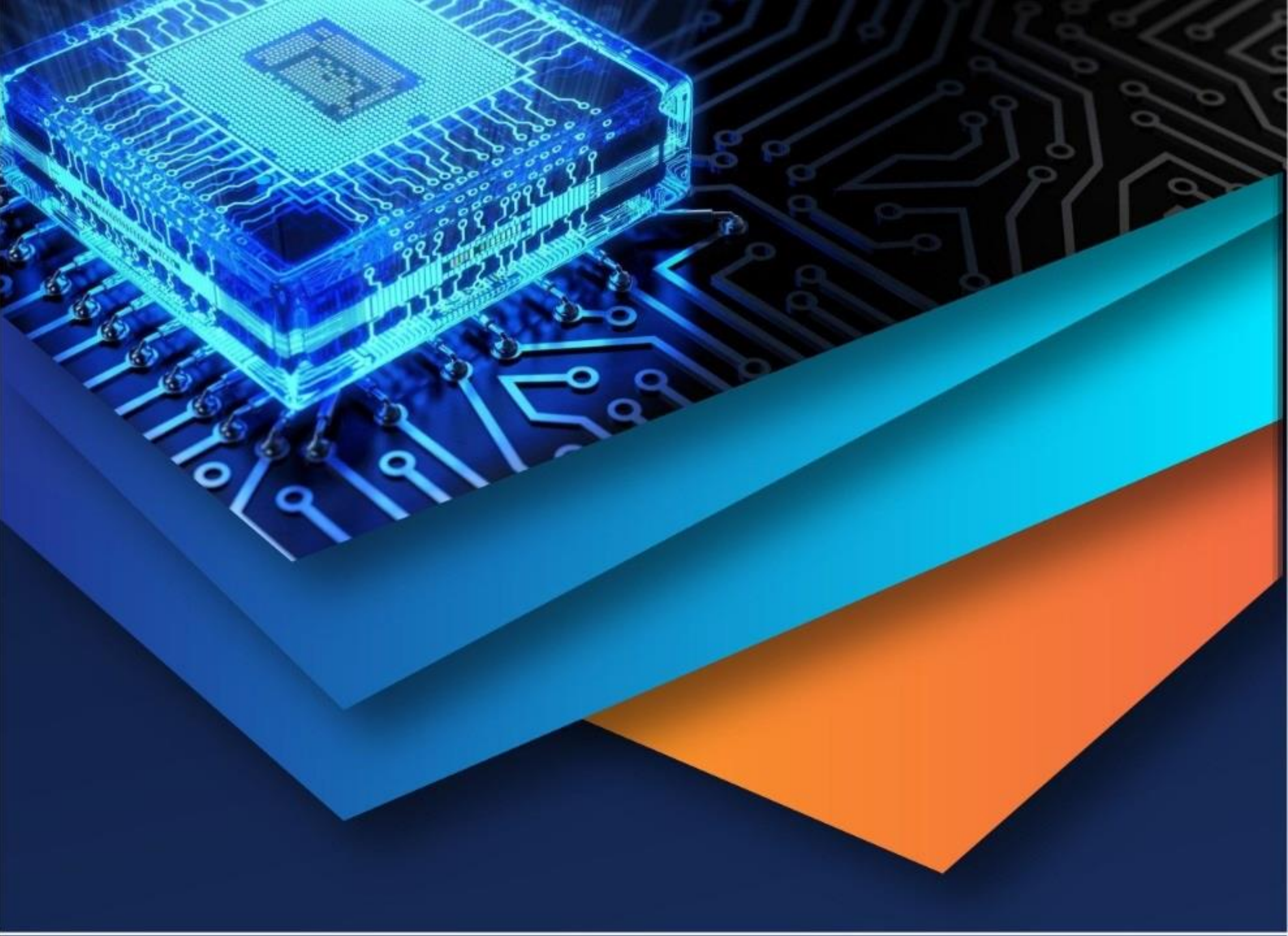

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