OmniSense-Dual -- Navigation Vest Suite for People with Eye Disability

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Abstract

OmniSense-Dual is a dual-wearable pedestrian assistance system that provides 360° blind-spot hazard awareness and hands-free navigation without relying on vision or audio. A waist/belly-mounted module uses mmWave radar and ToF/ultrasonic sensing to detect approaching objects and nearby obstacles around the torso, while a lightweight head-mounted band provides directional haptic hazard alerts for head-level intrusions. Navigation cues are delivered only on the belt via distinct, gentle vibration patterns derived from phone-provided waypoints and IMU heading, preventing confusion with urgent hazard warnings. This report describes the system architecture, sensing and haptic interfaces, hazard logic, and verification criteria including detection recall, alert latency, navigation accuracy, and usability constraints such as battery life and total mass.

Contents

1. Introduction ... iii
1.1 Problem ... iii
1.2 Solution ... iv
1.3 Visual Aid ... v
1.4 High-level requirements list ... vi
2 Design ... vii
2.1 Block diagram ... vii
2.3 Subsystem requirements ... ix
2.4 Tolerance Analysis ... ix
3. Ethics, Safety, and Societal Impact ... x

1. Introduction

Pedestrians in urban and campus environments frequently share space with bicycles, e-scooters, cars, and other pedestrians. Unlike drivers, pedestrians typically lack rear-view awareness tools, and distractions (headphones, phones) further reduce situational awareness. Meanwhile, navigation often requires looking at a phone or listening to voice guidance—both attention-demanding and sometimes unsafe. Our device addresses these gaps by combining 360° hazard sensing with clearly separated, non-visual and non-auditory haptic feedback for navigation and warnings.

1.1 Problem

Pedestrians frequently experience unprotected blind spots in urban and campus environments, where fast-approaching objects from behind or diagonal directions are often noticed too late, particularly on shared paths and narrow sidewalks. Situational awareness is further reduced when pedestrians use headphones or smartphones or move through crowded environments, which degrade both auditory and visual perception and make nearby hazards more difficult to detect. In addition, navigation itself imposes a cognitive burden, as pedestrians must frequently check maps or listen to voice guidance, diverting attention from their surroundings. Audio-only navigation can also be problematic for visually impaired users who already rely heavily on auditory cues, further increasing the risk of missing environmental hazards.

1.2 Solution

We propose OmniSense-Dual, a dual-wearable system providing both hazard awareness and hands-free navigation through spatially separated haptic feedback.

The system consists of:

1. A waist-mounted module that performs environmental sensing, computation, navigation processing, and navigation haptic feedback.
2. A head-mounted module dedicated exclusively to hazard alerts through directional vibration.

The key design decision is to separate feedback channels:

- Head feedback = hazards only
- Belly feedback = navigation only

This separation ensures that users can instantly distinguish between danger warnings and navigation instructions.

The waist module uses mmWave radar and distance sensors to detect approaching objects around the user, while navigation instructions are provided through gentle vibration cues corresponding to turning directions. Hazard warnings are delivered through directional vibrations on the headband, allowing users to quickly perceive the direction of danger.

The solution aims to improve pedestrian safety and reduce cognitive load while supporting hands-free navigation in campus and urban environments.

1.3 Visual Aid

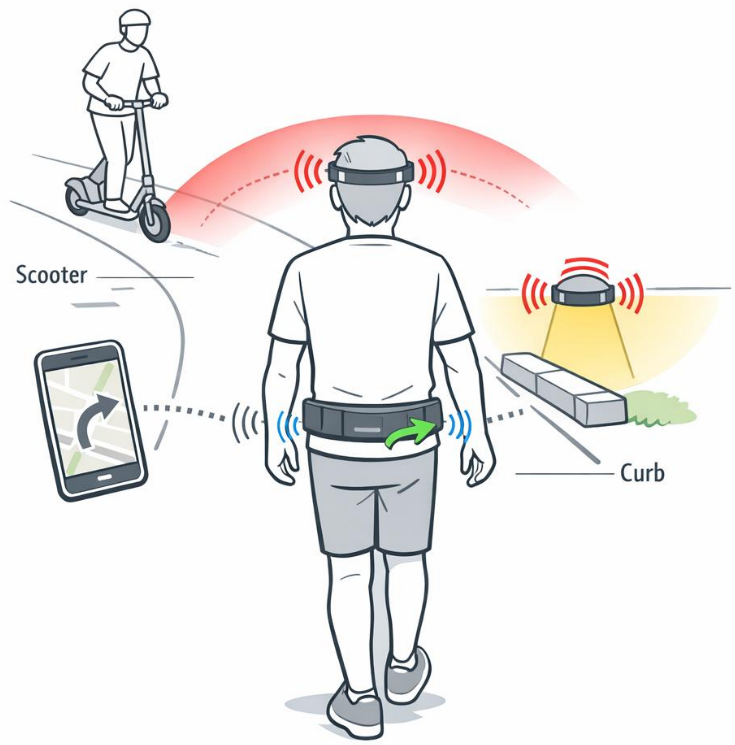

Figure 1. OmniSense-Dual operation example showing navigation cues delivered through waist vibrations while hazard alerts from approaching vehicles or obstacles are communicated via directional head-mounted vibrations.

Figure 1 illustrates the operational concept of the OmniSense-Dual pedestrian safety and navigation system. A user walks while wearing a waist-mounted sensing and navigation module together with a head-mounted hazard alert module. The waist module continuously monitors the surrounding environment using embedded sensors while receiving navigation instructions from a connected smartphone application. Navigation cues are delivered through gentle vibrations on the belt, guiding the user in the desired direction without requiring visual attention to the phone.

At the same time, hazards such as a fast-approaching scooter from behind or obstacles in the walking path are detected by the sensing system. When a hazard is identified, the head-mounted module produces directional vibration feedback corresponding to the location of the danger. This allows the user to quickly perceive where the threat is coming from without needing to look around or rely on audio warnings.

The figure also demonstrates the key design principle of OmniSense-Dual: navigation guidance is delivered only at the waist, while hazard alerts are delivered only at the head. This separation ensures that users can intuitively distinguish between movement instructions and safety warnings, improving situational awareness while walking in shared urban environments.

1.4 High-level requirements list

1. Safety Requirement: The system shall detect approaching hazards (bicycles, e-scooters, pedestrians) with ≥90% recall at distances ≥5 meters and provide directionally accurate haptic alerts to the user's head module, ensuring 360° coverage through dual-plane sensing (belly and head modules).
2. Navigation Requirement: The system shall provide hands-free, non-visual navigation guidance with ≥85% turn accuracy through the belly haptic interface, maintaining heading deviation ≤10° during straight-line navigation, with update latency ≤200ms from position change to haptic feedback.
3. Channel Separation Requirement: The system shall maintain distinct and unambiguous feedback channels where the head module exclusively provides hazard alerts and the belly module exclusively provides navigation cues, achieving ≥90% user classification accuracy between hazard and navigation signals to prevent confusion during simultaneous alerts.

2 Design

2.1 Block diagram

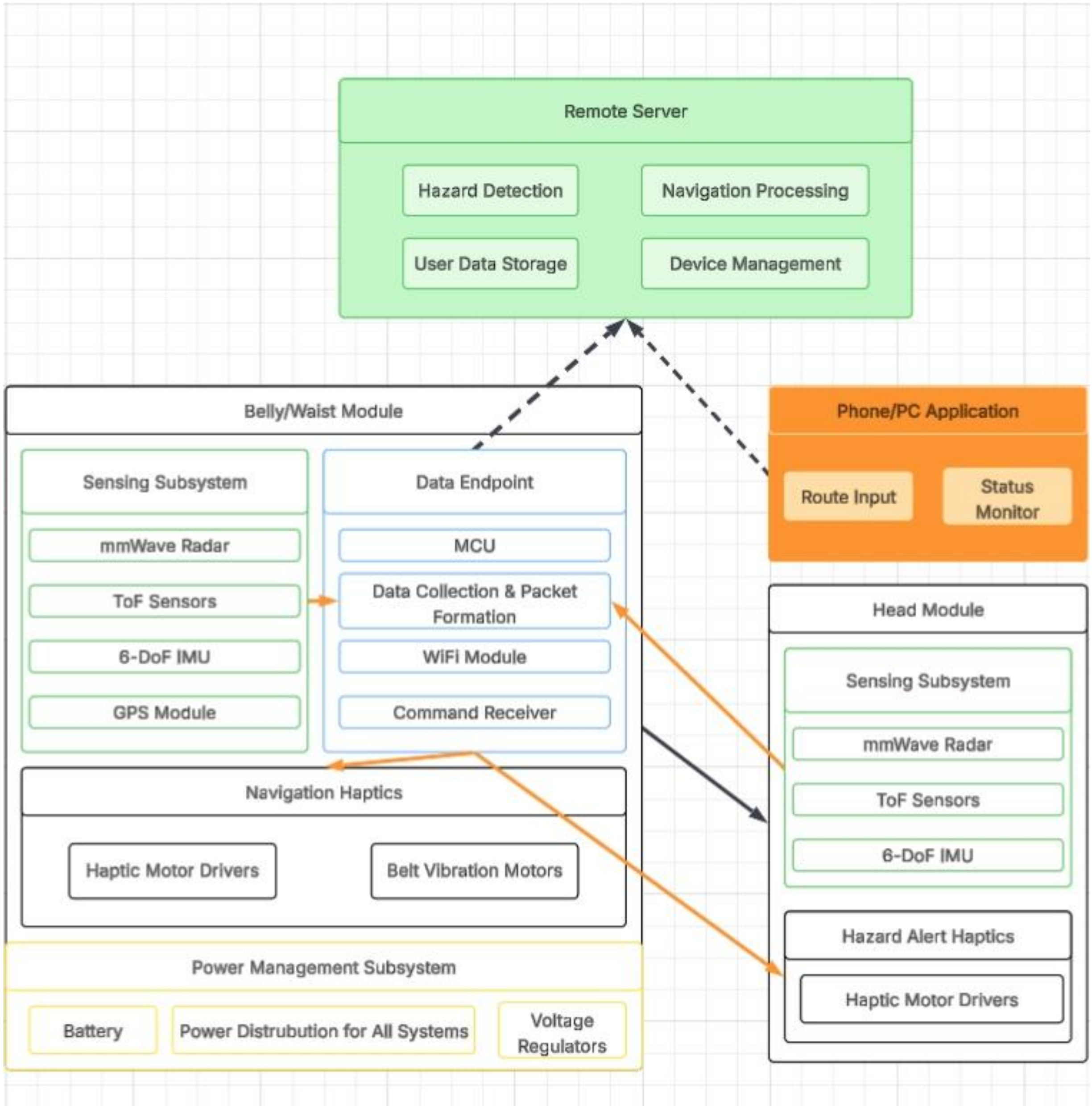

Figure 2. The Block Diagram of OmniSense-Dual system

The OmniSense-Dual system consists of three main hardware components along with two supporting external components. The Belly/Waist Module serves as the primary sensing and computation unit, collecting environmental and motion data while coordinating communication with other subsystems. A Head Module provides hazard alerts through directional haptic feedback. A dedicated Power Management Subsystem supplies regulated power to all electronics. In addition, a Phone or PC application provides route input and device monitoring, while an optional Remote Server supports navigation processing, device management, and data storage. Communication occurs wirelessly between modules and external components, enabling real-time hazard detection and navigation guidance.

2.2 Subsystem Overview

The Belly/Waist Module functions as the core processing component of the system. It integrates multiple sensors, including mmWave radar, time-of-flight distance sensors, an inertial measurement unit, and GPS, to observe the surrounding environment and track user movement. Data collected from these sensors is processed by an onboard microcontroller, which evaluates hazard conditions and computes navigation instructions received from the smartphone application. The module also drives navigation haptic feedback through belt-mounted vibration motors and transmits hazard information to the head module.

The Head Module is dedicated to delivering hazard alerts to the user. It receives processed hazard direction data from the belly module and activates vibration motors positioned around the head to indicate the direction of potential danger. This module may also include additional short-range sensing to detect obstacles at head height, further improving safety in crowded environments.

Navigation feedback is provided through the Navigation Haptics Subsystem embedded within the waist module. Instead of using audio or visual cues, navigation instructions are conveyed through gentle vibration patterns on different sides of the belt, allowing users to receive guidance while keeping their attention on their surroundings. Hazard alerts are intentionally separated and delivered only through the head-mounted subsystem to avoid confusion between navigation and danger warnings.

The Power Management Subsystem ensures reliable operation of all modules by supplying regulated voltage from a rechargeable battery source. This subsystem includes charging circuitry, voltage regulation, and distribution circuits to provide stable power to sensing, processing, communication, and haptic components throughout extended operation periods.

The Phone or PC application enables users to input routes and monitor device status while transmitting navigation instructions to the wearable modules via wireless communication. In addition, an optional Remote Server infrastructure may provide route computation, user data storage, and device management services, supporting scalable future development of the platform.

2.3 Subsystem requirements

The sensing capabilities of the belly module must be sufficient to detect hazards at distances of at least five meters to allow users enough time to react. Distance sensors must reliably detect nearby obstacles, while the inertial measurement unit must provide accurate heading updates to maintain navigation precision. GPS positioning is required for outdoor navigation scenarios, ensuring that route information aligns with user movement.

The onboard microcontroller must process sensor updates and communication packets quickly enough to maintain low system latency, ensuring that hazard alerts and navigation cues are delivered without noticeable delay. Communication reliability between modules must also remain high so that commands and status updates are not lost during operation.

The navigation haptic system must produce vibration signals that are strong enough to be perceived through clothing while remaining comfortable for continuous wear. Directional feedback must be clear so users can intuitively interpret navigation cues without visual confirmation.

Similarly, the hazard alert subsystem in the head module must activate directional vibration motors quickly and distinctly, allowing users to perceive danger direction without ambiguity. The design requires sufficient motor placement coverage around the head to provide intuitive spatial awareness.

Stable operation of all subsystems depends on reliable power delivery. Therefore, the power management system must maintain regulated voltage levels and supply sufficient current during peak operation while supporting several hours of continuous use.

2.4 Tolerance Analysis

A major technical challenge of the system is ensuring reliable hazard detection under varying environmental conditions such as sensor occlusion, reflective surfaces, and interference. Consider a scenario in which a user walks at approximately 1.5 meters per second while a scooter approaches from behind at six meters per second. The relative closing speed becomes approximately 7.5 meters per second. If the system detects the hazard at a distance of five meters, the available reaction time is approximately 0.67 seconds. After subtracting system processing latency, which is designed to remain below 250 milliseconds, the user still has sufficient time to respond to the alert. By combining radar sensing with distance sensors and filtering techniques, detection reliability can remain above required thresholds even in challenging environments.

3. Ethics, Safety, and Societal Impact

The OmniSense-Dual system is designed to improve pedestrian safety and situational awareness in environments where pedestrians share space with bicycles, scooters, and vehicles. Because the system directly influences user behavior in potentially hazardous environments, ethical and safety considerations must be addressed carefully during both development and deployment. According to the IEEE Code of Ethics, engineers are required to prioritize public safety, avoid misleading claims, and design systems that minimize risk to users and society. To align with these principles, the project avoids presenting the device as a replacement for user awareness; instead, it is intended only as an assistive tool. Documentation and user instructions will clearly communicate system limitations so that users do not become overly dependent on the device.

Several safety concerns arise from both hardware design and system operation. The system uses rechargeable batteries and wearable electronics, which introduce potential risks such as overheating, electrical faults, or discomfort during prolonged wear. These risks are mitigated by using regulated power circuits, proper battery protection modules, and safe enclosure designs that prevent direct exposure to electrical components. Vibration motors are also limited in intensity to avoid discomfort or distraction that could itself create unsafe situations. During development and testing, all hardware will follow standard laboratory safety practices to protect team members from electrical hazards and mechanical failures.

Potential misuse must also be considered. For example, users might rely entirely on the system and pay less attention to their surroundings, or the device could be incorrectly used in environments beyond its sensing capability. To reduce these risks, the system design emphasizes conservative hazard detection thresholds and encourages users to maintain normal situational awareness. Furthermore, the system does not collect or transmit personally identifiable data, reducing privacy concerns associated with wearable sensing devices. Sensor data are processed locally and used only for real-time hazard detection and navigation guidance.

From a societal perspective, the system has the potential to positively impact urban mobility and accessibility by helping pedestrians navigate safely and by providing additional assistance for visually impaired users. As cities adopt more micro-mobility solutions such as scooters and bicycles, conflicts between pedestrians and vehicles are expected to increase. A wearable awareness system can help reduce accidents and improve coexistence on shared paths. Economically, the system leverages relatively low-cost sensors and consumer electronics, making future deployment feasible for broader populations. Environmentally, the device has minimal impact beyond standard consumer electronics usage, though responsible disposal and battery recycling practices should be encouraged.

Overall, OmniSense-Dual aims to enhance public safety while respecting ethical responsibilities, minimizing risks to users, and supporting safer and more inclusive pedestrian environments.

4. Reference

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