Multi Directional Haptic Feedback Belt

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Abstract— **In this paper, we present a multi-directional haptic belt that uses torso vibrotactile feedback to direct navigation cues in indoor environments where visual or auditory guidance may be unreliable. The system encodes both direction and distance to a target using four evenly spaced ERM motors placed around the waist. The system combines UWB ranging with inertial sensing to estimate user heading and relative position to anchors, then maps to intuitive vibration patterns across four motors placed around the waist. Custom firmware and a visualization tool enable real-time computation, tuning of vibration profiles, and evaluation of direction and distance encoding. Preliminary tests indicate that the belt produces consistent heading-dependent patterns and responsive distance modulation, while also revealing practical issues such as motor coupling, range jitter, and IMU drift that guide future refinements and planned user studies.**

Keywords — haptics, wearable devices, vibrotactile feedback, indoor navigation, ultra-wideband (UWB), inertial measurement unit (IMU), eccentric rotating mass (ERM).

Demonstration: https://drive.google.com/file/d/1ZoU-Zdga8CJASF_LFWYx2t_xeVVMmjxM/view?usp=sharing

I. Introduction

Indoor navigation is difficult when vision and hearing are unreliable, such as in smoke-filled buildings, disaster sites, crowded transit hubs, or daily mobility for people with visual impairments. In these settings, people must keep track of their orientation, locate targets, and make time-critical decisions with limited situational awareness. Haptic guidance offers a promising alternative to convey spatial information without competing with visual or auditory channels through compact, body-worn systems. SearchSense, for example, uses a wearable haptic interface to guide urban search-and-rescue personnel toward victims by estimating the direction of radio-frequency emissions from cell phones, showing that simple directional vibrations can support navigation in degraded environments [1]. At the same time, work in indoor positioning has mapped the design space of technologies such as Wi-Fi, Bluetooth Low Energy (BLE), radio-frequency identification (RFID), and UWB, and has highlighted key trade-offs between accuracy, cost, and power consumption that shape haptic navigation systems [2].

The torso is an attractive site for conveying spatial information due to a large surface area and being near the body's egocentric reference frame. Multimodal haptic vests have shown that arrays of torso-mounted actuators can encode direction and intensity through carefully chosen spacing and combinations of vibrotactile, tapping, and thermal cues [3]. Earlier vibrotactile belts, such as the modular system developed by Rosenthal et al., demonstrated that distributed tactors around the waist can deliver spatial and temporal information with high cue recognition while maintaining comfort during extended wear [4]. Long-term studies with the feelSpace vibrotactile belt showed that a continuous tactile indication of magnetic north can become integrated into spatial cognition, reducing discomfort and increasing confidence in complex everyday navigation tasks for blind users [5]. These studies suggest that rings or arrays of actuators on the torso can provide intuitive directional cues, yet many existing designs rely on preprogrammed patterns or simple heading signals rather than exploiting fully closed-loop interaction with the environment.

Together, these advances point toward belt-mounted systems that fuse IMU and UWB (or BLE) measurements in real time and translate bearing and distance estimates into tactile patterns. Motivated by this gap, our project explores a multi-directional haptic belt that encodes both direction and distance to an indoor target through vibrotactile cues around the waist. The belt uses a ring of ERM motors to stimulate the torso and a compact embedded platform that combines UWB ranging with IMU-based orientation sensing. By computing the bearing to an anchor or tagged object in the wearer's reference frame, the system maps angular offset into spatially distributed vibration patterns and scales intensity with estimated range. In contrast to earlier belts that provide static cues or only heading information, this design aims to deliver continuous, closed-loop guidance while remaining lightweight and wearable. The prototype serves as proof of concept that ties established findings in torso haptics and indoor localization to a practical, real-time multi-directional guidance interface and provides a foundation for future user studies of directional accuracy, workload, and usability.

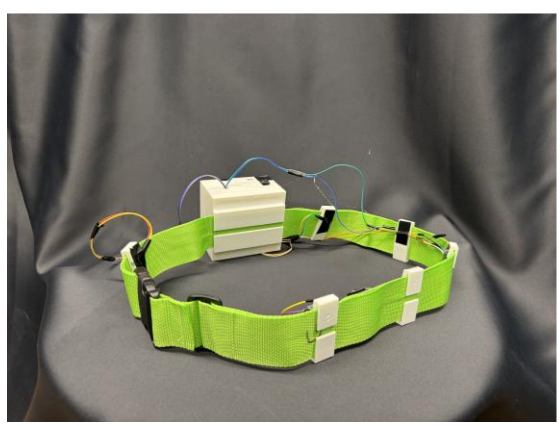

Figure 1: Constructed belt prototype

II. METHODS

A. Device Description

The prototype is a wearable, torso-mounted vibrotactile belt that delivers cutaneous feedback on the waist. Four ERM motors are mounted at approximate cardinal directions on a nylon webbing belt to represent north (front), east (right), south (back), and west (left). The belt is intended to stimulate primarily Pacinian corpuscles, with some recruitment of Meissner corpuscles, through low- to mid-frequency vibrations on the skin. A 3D-printed control box mounted near the wearer's right hip houses the electronics, battery, calibration button, and main power switch. The assembled device is shown in Fig. 1.

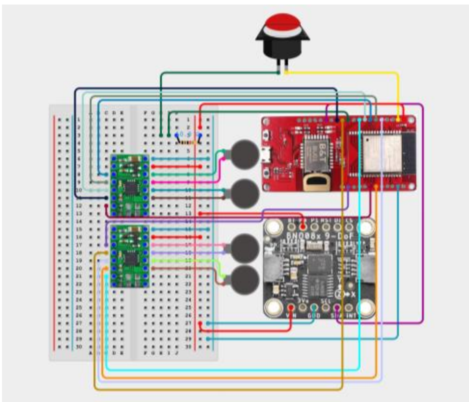

Figure 2: Full circuit diagram

The belt electronics are built around a Makerfabs ESP32 UWB Pro board, which integrates an ESP32-WROVER microcontroller, a Decawave DW1000 UWB transceiver, and an OLED display. An Adafruit BNO085 IMU in UART-RVC mode provides real-time yaw estimates, which are used to keep the haptic feedback aligned with the wearer's heading. Two DRV8833 dual H-bridge drivers control the four ERM motors, with separate high-side PWM channels and low-side enable lines to support independent amplitude modulation. Power is supplied by a single-cell lithium-ion battery with an onboard charging circuit and status LED, so the belt can operate untethered during demonstrations. These components are placed in a 3D printed enclosure. The full circuit diagram is shown in Fig. 2.

Figure 3: UWB anchor node

A separate UWB anchor node provides the reference point that the belt "seeks." The anchor uses the same Makerfabs ESP32 UWB Pro hardware but runs dedicated firmware to act as a fixed responder. It is powered through a USB connector and displays its status on the integrated OLED (with anchor ID and prompts like "waiting for TAG…"). The anchor is typically placed on a table or tripod at torso height in front of the user and is shown in Fig. 3. This separation between a mobile tag and static anchor simplifies the geometry and isolates haptic feedback to the tag side.

B. Sensing, Control, and Calibration

On power-up, the belt executes a setup pattern that allows the experimenter to confirm that all four tactors are wired and mounted correctly before calibration. Shows the IO of the device where the user will be interacting to turn on and calibrate. The firmware then enters a ranging and orientation loop that continuously queries the DW1000 for distance to the anchor and reads yaw from the IMU.

To define the reference frame, the user stands a short distance directly facing the anchor and presses a red calibration button on the control box. At that instant the current yaw angle is stored as the "anchor facing" orientation. Subsequent yaw readings are expressed relative to this baseline. The front motor briefly vibrates after the button press to confirm that calibration has been accepted.

During normal operation, the firmware maps the estimated bearing to a pair of adjacent motors and uses cosine-weighted interpolation to distribute vibration between them. When the user faces the anchor, the front motor carries most of the vibration; as the user turns, the energy shifts smoothly toward the right, back, or left motors. The amplitude is also scaled as a simple function of UWB distance, so closer positions produce stronger vibrations and distant positions feel weaker or may fall below a minimum threshold. The control loop runs at interactive rates on the ESP32, which keeps the haptic feedback responsive to natural head and body movements. Safety considerations include limiting maximum duty cycle to avoid motor overheating and using conservative charge and discharge currents for the Li-ion battery.

C. Preliminary Results

Bench testing confirmed that the belt's motors respond to the expected direction sequence at startup and that the calibration procedure reliably aligns the "north" motor with the anchor direction. Serial monitoring showed stable yaw estimates from the BNO085 under slow rotations and consistent UWB range readings within the typical indoor line-of-sight distance used in our demos. When the bearing-to-motor mapping was enabled, sweeping the belt through 360° produced continuous shifts in the dominant motor, with no abrupt jumps between cardinal directions.

Informal wear tests by the project team indicated that the belt conveys directional cues that qualitatively match the anchor's location and that distance-dependent scaling is noticeable, though subtle, at shorter ranges. The use of a single belt-mounted control box and nylon strap provided acceptable comfort for short sessions and allowed rapid donning and doffing. At the same time, prototype limitations became apparent. Two motors were stronger than the other two due to hardware damage, which led to uneven perceived intensity across directions, and mechanical coupling through the belt sometimes blurred the boundary between adjacent tactors. We also observed jitter in UWB range estimates and gradual drift in yaw during extended motion, which can degrade directional accuracy. These findings suggest that future iterations should use matched motors, improved mechanical isolation, and more advanced filtering or sensor fusion to stabilize the haptic cues for longer and more demanding navigation tasks.

III. FUTURE WORK

A. *Future Development*

Several practical limitations of the current prototype suggest clear directions for hardware and software improvement. Damaged ERM motors led to uneven intensity across directions. Next iteration would use more durable ERMs vibration modules. Additionally, better cable routing to reduce mechanical stress on solder joints. The present design runs all motors from the ESP32's 3.3V, but the stronger ERMs are specified for 3.7 V. A dedicated power stage with an appropriate boost converter, or a separate motor supply would allow each tactor to reach its intended amplitude for increased reliability. The current tag–anchor pair could be extended to a multi-anchor configuration to increase functionality. Multiple anchors would let us encode waypoints as distinct vibration patterns. In parallel, belt-to-belt communication could provide situational awareness within a team, with each belt broadcasting its position so that users feel the relative direction of their partners. Improved distance estimation, through refined UWB ranging and filtering, would allow more graded intensity changes and a clearer sense of approach or separation. Future iterations will also focus on making the belt lighter and more compact, exploring flexible PCBs and slimmer enclosures so the device can be worn under or over clothing without interfering with normal movement.

B. *User Study Protocol*

To evaluate the belt, we propose a system performance study with healthy adult participants. A sample of 20–24 volunteers aged 18–40 years, with no known vestibular or significant tactile impairments, would provide sufficient power for within-subject comparisons. The study would take place in a controlled indoor environment with movable partitions that form simple corridors and junctions. Participants would first complete a short training session to learn the mapping between vibration patterns and directions. During all test trials they would wear vision-occluding goggles and noise-masking headphones so that navigation relies primarily on the haptic cues.

Each participant completes two main tasks. In a seated "direction identification" task, the belt would present a series of static cues corresponding to discrete bearings (for example front, right, back and left or eight cardinal directions). Participants would indicate the perceived direction using a handheld response device or by pointing, which isolates the mapping accuracy of the belt without locomotion. In a walking "guided navigation" task, participants would start at a fixed location and use the belt to walk toward one or more hidden anchors along pre-defined paths with straight segments and turns. Path layouts would be randomized across trials to reduce learning effects. Short rest periods would be included between blocks, and the total session time would be kept under one hour to limit fatigue. This protocol provides a reproducible sequence of instructions that every participant follows, while capturing both local cue interpretation and functional navigation.

C. *Evaluation Metrics*

The study would combine quantitative and qualitative metrics. In the direction identification task, the primary quantitative measures would be percent correct direction judgments and median response time for each bearing. In the navigation task, we would record completion time, number of wrong turns or collisions with obstacles, and lateral deviation from the ideal path measured from floor markers or motion capture. These measures directly assess how well the device converts sensor data into useful guidance.

Qualitative data would be collected through post-experiment questionnaires and short interviews. Participants would rate feedback intuitiveness, perceived task difficulty, comfort, and confidence in the cues on Likert scales. They would also compare conditions such as "belt on" versus "no belt" and indicate their preferred configuration. Open-ended questions would solicit comments about uneven vibration strength, interference from clothing and confusion with distance changes. This combination of metrics would provide a view of system performance and user experience, guiding design choices for future iterations.

D. *Conclusion*

This project demonstrated a wearable multi-directional haptic belt that combines UWB ranging, inertial sensing and vibrotactile actuation to convey egocentric directional and distance cues around the waist. The prototype established a complete pipeline from sensor measurements to motor control and produced stable, heading-dependent vibration patterns in informal tests, but it also revealed important limitations in actuator robustness, power delivery and sensing fidelity. The planned hardware refinements and the proposed user study are aimed at turning this proof of concept into a more durable, perceptually consistent and quantitatively validated navigation aid. With improved ERMs, better power architecture, multi-anchor support and belt-to-belt communication, the system has the potential to become a compact platform for studying haptic navigation in realistic team-based scenarios and for supporting situational awareness when visual and auditory channels are constrained.

IV. REFERENCES

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