Magnetometer-based orientation and tactile feedback navigation for a robot guide dog

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Abstract—Navigation assistance for Blind and Visually Impaired (BVI) individuals using robot guide dogs requires precise orientation feedback. Existing systems rely on audio cues, which are unreliable in noisy environments, or vibration feedback, which is uncomfortable over time. We present a novel prototype that integrates two CMPS14 magnetometers with a tactile feedback system embedded in a glove-style leash to guide users by sensing the relative heading between the user and the robot dog. Unlike inertial measurement units (IMUs), which suffer from drift, magnetometers provide a stable absolute reference via the Earth's magnetic field. A user study with six participants demonstrated that tactile feedback reduced average heading error by 32% and improved task completion time by 18% compared to audio feedback. All participants found the system intuitive and easy to use.

I. Introduction / Background (Sytle: Heading 1)

Vision impairment affects an estimated 2.2 billion people worldwide [1]. While guide dogs have long supported BVI individuals, their high cost and limited availability restrict access [2]. Robotic guide dogs have emerged as a scalable alternative, offering AI-driven navigation and sensor-based assistance [3][4].

Current systems typically relay directional information through audio or vibration cues. Audio feedback can be ambiguous or overwhelming in real-world environments [5], while prolonged vibration causes discomfort [6]. Orientation accuracy also remains a challenge: systems using inertial measurement units (IMUs) accumulate drift errors over time [7], degrading heading precision.

This paper presents a prototype that addresses these limitations by using high-precision magnetometers for drift-free orientation tracking and compact DC linear actuators for tactile directional feedback. To our knowledge, this is the first system to use magnetometers as the primary orientation mechanism in a robot guide dog context.

II. Related Work

Smart cane systems have been widely explored. Messaoudi et al. developed an autonomous indoor navigation cane [8], while Slade et al. combined LiDAR and GPS for multimodal guidance [9]. Kayukawa et al. extended smart cane technologies to museum environments [10], though participants noted excessive weight.

Quadruped robot guide dogs have gained traction. Chen et al. explored comfort-centred guidance combining haptic feedback with voice commands [11]. The Cabot robot demonstrated autonomous indoor navigation for blind users [12]. RDog [13] used LiDAR, IMU, and cameras with voice alerts and force feedback via a rigid leash, outperforming cane-based systems but lacking precise orientation tracking in unmapped or dynamic areas. Wang et al. [14] proposed a multimodal haptic walker interface for assisted navigation.

A common limitation across all reviewed systems (see Table 1) is imprecise left/right orientation guidance, leading to user confusion during turns. Our system specifically addresses this gap.

III. Prototype Description

A. Hardware components

The prototype is built around the DeepRobotics Lite3 quadruped robot dog. Two CMPS14 magnetometers form the sensing core. The CMPS14 is a fifth-generation tilt-compensated compass module integrating a 3-axis magnetometer, gyroscope, and accelerometer (BNO080 processor). It operates at 3.3–5 V, draws 18 mA, and provides 16-bit heading, pitch, and roll outputs. Unlike IMUs, the CMPS14 uses the Earth's magnetic field as a constant reference, eliminating cumulative drift [7].

One CMPS14 is worn by the user at the waist—identified as the most stable body location for sensor placement [15]—and a second is mounted on the robot dog. An Arduino Uno R4 WiFi (ESP32-S3-MINI-1) reads both sensors and computes the relative heading difference in real time.

Directional cues are delivered via three HU287 DC linear actuators (1 cm × 5.5 cm, 3–5 V) embedded in a glove-style leash held by the user. Two L298N H-bridge motor drivers control the actuators. The left and right actuators signal turn directions; the centre actuator signals forward movement. The system activates the relevant motor when the heading difference between user and robot exceeds a 15° threshold.

B. Prototype construction

The waist-mounted CMPS14 is housed in a 3D-printed clip that attaches to a belt. The leash integrates the three actuators into a glove-style handle using heat-shrink tubing and foam padding to maintain user comfort during extended use. The Arduino processes sensor data via I2C and drives the motor controllers through digital GPIO pins. All components are powered from a 5 V USB power bank worn by the user.

A Python data logging script runs on the robot dog's onboard computer to record heading readings from both magnetometers in parallel, enabling post-hoc performance analysis.

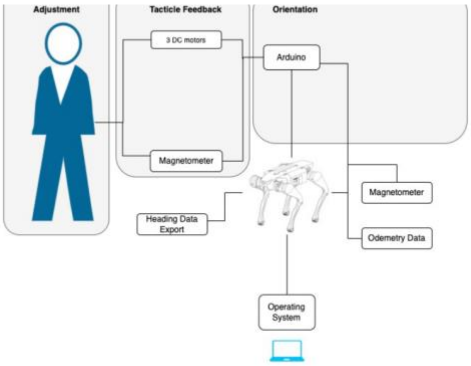

Fig. 1. Schematic representation of the robot guide dog system's interaction

Fig. 1. System interaction design: user magnetometer at waist, robot magnetometer, Arduino processing unit, and three DC actuators in the glove leash.

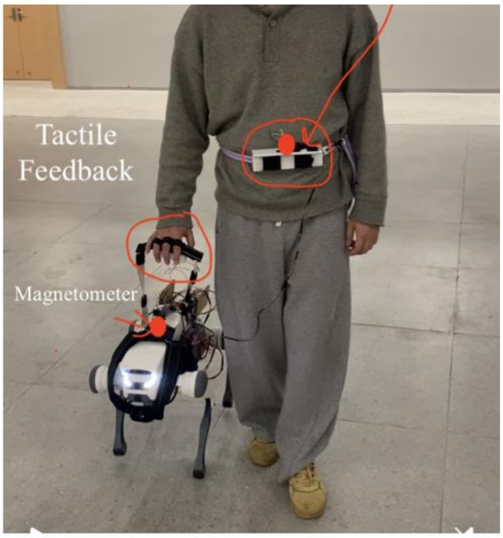

Fig. 2. Schematic representation of the robot guide dog system's interaction design.

Fig. 2. Participant wearing the system: waist-mounted CMPS14 magnetometer and glove-style leash with embedded tactile actuators.

IV. Evaluation

Six healthy participants with no visual impairments were recruited and blindfolded to simulate BVI conditions. Two tasks were performed: Task 1 used audio feedback (verbal turn instructions); Task 2 used the tactile feedback system. Each task involved three turning angles: 45°, 90°, and 180°. The experiment took place in a quiet room. Performance was measured by heading difference (precision) and task completion time.

A Wilcoxon signed-rank test showed that tactile feedback significantly outperformed audio feedback overall: heading error was reduced by 32% ($p = 0.003$, CLES = 0.88) and task completion time was 18% shorter ($p = 0.021$, CLES = 0.72). The improvement was especially pronounced for 45° turns, where average heading error fell from 72.12° (audio) to 20.18° (tactile), and for 180° turns ($p = 0.003$, CLES = 0.96). All six participants agreed or strongly agreed that the tactile cues were intuitive, easy to follow, and provided precise orientation guidance.

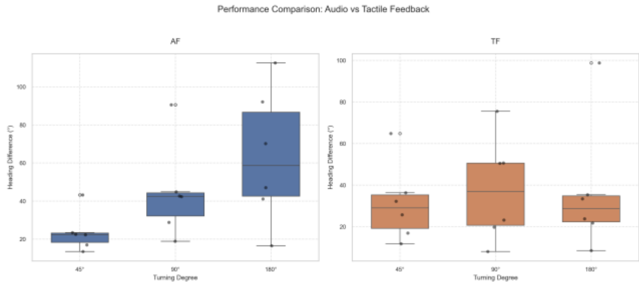

Fig. 3. Table II. Heading differences (degrees) and time costs (seconds) for audio feedback (Task 1) and tactile feedback (Task 2) across three turning angles.

Task	Turn Right 45°	Time Cost	Turn Left 90°	Time Cost	Turn Right 180°	Time Cost
Task1	72.12	19.65	24.35	18.46	31.98	16.65
Task2	20.18	16.89	20.58	17.28	7.65	15.78

Fig. 4. Performance comparison: tactile feedback (TF) achieves significantly lower heading differences than audio feedback (AF) for a 90° turn.

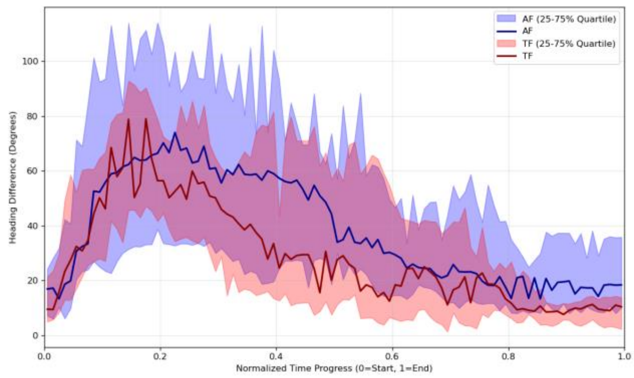

Fig. 5. Quartile analysis of heading differences over normalised task time. TF (red) shows a narrower range than AF (blue), indicating greater consistency.

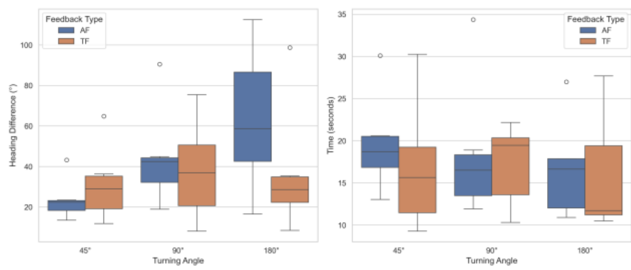

Fig. 6. Heading differences and time costs for both feedback types across all three turning angles (45°, 90°, 180°).

V. Responsible Innovation

This prototype is designed to directly benefit a marginalised group: the 2.2 billion people worldwide with some form of visual impairment. Replacing guide dogs with affordable robotic alternatives could democratise access to independent mobility. Future work will prioritise user studies with actual BVI individuals to ensure the system meets real-world needs rather than assumed ones.

From a sustainability perspective, the components used (CMPS14, Arduino, small DC actuators) are low-power and widely available. The magnetometer-based approach avoids the high energy consumption of continuous camera or LiDAR processing. Miniaturisation in future iterations would further reduce power demand. We aim to use off-the-shelf, replaceable parts to extend product lifetime and reduce electronic waste.

Potential risks include magnetic interference in urban environments (e.g., near large metal structures), which we plan to mitigate through sensor fusion with visual odometry. We are also mindful of the social implications of deploying robotic guides in public spaces and will engage BVI communities early in the design process.

VI. Author bio

Malek Arous completed his Master's degree in October 2025. His thesis focused on hardware development for assistive robotics, where he built a full navigation workflow for a quadruped robot dog using Arduino-based tactile feedback and LiDAR-based SLAM. The work in this paper was developed in parallel during a research stay in China through the Global Research Immersion for Young Scientists programme at Zhejiang University, Hangzhou, where he collaborated with researchers on sensor integration and human–robot interaction for BVI navigation. The magnetometer-based prototype was submitted to the IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS) 2025.

His interests lie at the intersection of embedded systems, low-cost sensor hardware, and inclusive technology. He is motivated by the potential of robotics to remove barriers for people with disabilities and is keen to develop his prototyping skills further to take assistive devices from research proof-of-concept to reliable, manufacturable product.

VII. Acknowledgements

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VIII. References

[1] [1] World Health Organization, "World report on vision," 2021.

[2] [2] K. Wirth and D. B. Rein, "The economic costs and benefits of dog guides for the blind," Ophthalmic Epidemiology, vol. 15, pp. 92–98, 2008.

[3] [3] Q. Wang et al., "Smart seeing eye dog wheeled assistive robotics," ISRIMT, 2021.

[4] [4] D. R. Bruno et al., "Development of a mobile robot: Robotic guide dog for aid of visual disabilities," LARS/SBR/WRE, 2019.

[5] [5] T. Liu et al., "Characterizing and predicting engagement of blind and low-vision people with an audio-based navigation app," CHI Extended Abstracts, 2022.

[6] [6] M. Griffin and E. Whitham, "Discomfort produced by impulsive whole-body vibration," J. Acoust. Soc. Am., vol. 68, pp. 1277–1284, 1980.

[7] [7] M. V. Ornhag et al., "Trust your IMU: Consequences of ignoring the IMU drift," CVPRW, 2022.

[8] [8] M. D. Messaoudi et al., "Autonomous smart white cane navigation system for indoor usage," Technologies, vol. 8, p. 37, 2020.

[9] [9] P. Slade et al., "Multimodal sensing and intuitive steering assistance improve navigation for people with impaired vision," Science Robotics, vol. 6, no. 59, 2021.

[10] [10] S. Kayukawa et al., "How users, facility managers, and bystanders perceive a navigation robot for visually impaired people," RO-MAN, 2022.

[11] [11] Y. Chen et al., "Quadruped guidance robot for the visually impaired: A comfort-based approach," ICRA, 2023.

[12] [12] J. Guerreiro et al., "Cabot: Designing and evaluating an autonomous navigation robot for blind people," ASSETS, 2019.

[13] [13] S. Cai et al., "Navigating real-world challenges: A quadruped robot guiding system for visually impaired people," CHI, 2024.

[14] [14] Y. Wang et al., "Multimodal haptic interface for walker-assisted navigation," IROS, 2024.

[15] [15] "An analysis on sensor locations of the human body for wearable fall detection devices," Sensors, vol. 16, p. 1161, 2016.