# In-Sight: Tension-Based Haptic Feedback to Improve Navigation for People who are Blind

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## CCS CONCEPTS

• **Human-centered computing → Haptic devices; Accessibility technologies;** *Accessibility systems and tools.*

## KEYWORDS

Navigation aid, force feedback, haptic feedback, assistive technology

## COPYRIGHT



## ABSTRACT

Current navigation assistants for people who are blind predominantly use vibration and sound to guide their users. While these modalities are effective, they represent the environment only indirectly. In contrast, force feedback, the simulation of virtual objects using force, is an emerging method to represent environments directly, as if the user is encountering them in the real world. To investigate the application of this new mode in navigation, we created In-Sight to present a virtual map of the user's surroundings using force feedback. This platform is intended to provide a similar perceptual response to the common white cane, while extending the depth range and removing the need to physically touch obstacles.

## INTRODUCTION

Wayfinding in unknown environments poses significant challenges for people who are blind. Navigation requires individuals to constantly combine their innate sensing and planning abilities to consider information about their position, velocity, and acceleration [6]. The white cane remains a common method for people who are blind to perceive their surrounding environment by gathering contextual information through force transmission and vibration.

Recent developments in sensing and computation are creating exciting opportunities to support people who are blind with technology, hopefully providing richer feedback with higher fidelity. Innovations in LiDAR and depth cameras have advanced the ability of computers to perceive the world with high resolution in a variety of environments and lighting conditions. Simultaneously, the miniaturization of sensors and computers has enabled the development of portable electronic devices, which has led to the rapid introduction of technology to assist people who are blind in navigation [1, 12].

Figure 1: Initial testing of In-Sight version 1.

Figure 2: Rendering of In-Sight hardware.

Combining traditional modalities, such as haptic feedback, with these advances has informed the development of In-Sight to evaluate whether force feedback is an effective mode of communication for navigation in unfamiliar environments. In-Sight uses tension applied to three strings to convert a LiDAR-generated point cloud into a tactile map (Figure 1). Our initial prototype was piloted on a small sample of sighted individuals, successfully enabling its users to navigate in a constrained environment. In this pilot study, we determined the effectiveness of In-Sight as a tool to represent planes and edges, which compose walls, structures, doorways and large obstacles in indoor navigation (Figure 3).

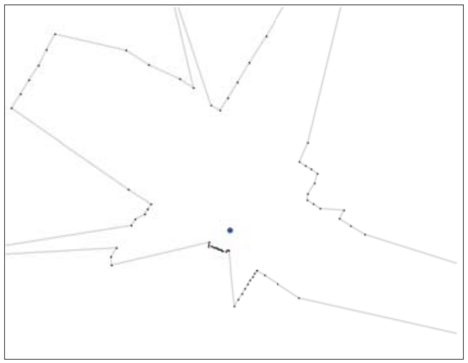
## LITERATURE REVIEW

Assistive navigation aids can be classified by how they gather information about the world and how they portray this information to the user. To gather information, aids use two general modes, global and local navigation. Global navigation systems use external devices to guide the user with respect to a predefined map; for example, NavCog uses pre-placed Bluetooth Low Energy beacons [1, 12]. In contrast, local navigation systems concentrate on lower-level path planning and obstacle avoidance, taking live input from the directly surrounding environment. Some systems concentrate on a specific type of activity, such as jogging, a mode of movement not well served by the white cane [11]. Others, such as NavGuide, are more general, providing information about obstacles and other hazards in a general setting [10].

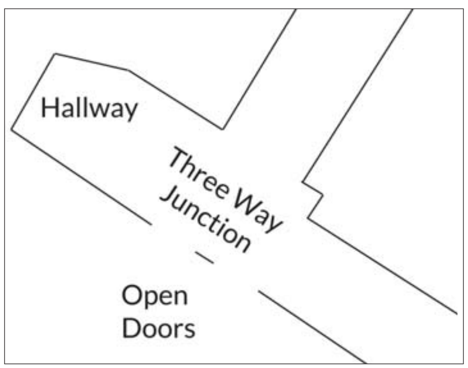
In order to portray information about the surrounding environment, both global and local devices use various feedback systems. Haptic feedback systems designed to convey information about environments take various forms: vibration (to convey simple but generally low resolution haptic feedback), tactile surfaces (to convey stimuli to a user via a fixed-position surface that can change shape or form), and force feedback (to provide dynamic forces applied to a user's hand as they explore a virtual arena). NavGuide is an example of a vibrationary system that uses six vibration motors to signal to users which direction they should walk [10]. Intelligent Glasses is an example of a tactile system that uses an eight-by-eight matrix of pins through which a person can manually feel a navigation map and comprehend the surrounding area [14]. In-Sight is an example of a force-feedback system that uses tension in strings to simulate forces from virtual objects.

Two close analogues to In-Sight's force-feedback mechanism are the WireMan [4] and the VIDET project [3]. Both systems, like In-Sight, use tension wires mounted at three points to pull on users' hands and provide virtual forces that model normal forces from surfaces in an environment. A similar system, SPIDAR-G, provides additional translational and rotational degrees of freedom implementing additional motors and wires [9, 13].

Force-feedback devices face several implementation issues, including the need for a very fast feedback loop and the need to mitigate any large forces that have the potential to damage the users' hand(s) [7, 8]. These issues, which are generally resolved using software solutions, along with limited portable computing, constrained force-feedback devices to be non-mobile until the last decade. The rapid development of portable computing power and improvements to motors and motor controllers in the past ten years have enabled us to create a wearable feedback device with fast feedback and significant forces in a small form factor.



**(a) LiDAR point cloud. The blue dot represents the user.**




**(b) Schematic of real-world location where (a) was taken.**

**Figure 3: A LiDAR point cloud provides a 2D map of the local environment.**

## IN-SIGHT

In-Sight uses a combination of a depth sensor and a three-wire force-feedback haptic interface to allow people who are blind to navigate independently without needing to physically contact obstacles (Figure 2). Although there have been systems in the field combining depth sensing and force feedback, we have not found any literature using this sort of device for navigation.

During an initial pilot study of In-Sight, we found that users were able to navigate through hallways relatively effectively while blindfolded using this device. These experiments with our low-cost prototype were cursory, but helped us evaluate the concept and understand the requirements for sensors, actuators, and mechanisms. Using the insight gained from this system, we are currently developing a new, more sophisticated system upon which we will run more rigorous user studies to properly evaluate its effectiveness.

### Sensing

The LiDAR used in the initial system provides a set of points in a ring around the user, in increments of approximately 4 degrees, whose distance corresponds to the nearest obstacle in that direction (Figure 3a). Plotting these polar coordinates on a plane gives a local, 2D map of the area the user is in (Figure 3b). Although limited, this form of mapping was sufficient for real-time local navigation and obstacle avoidance in simple environments.

In our next system, we plan to use a RGB depth camera, the Intel RealSense D435, to map the environment around the user. Receiving a 3D point cloud does not constrict our system's perception to a single plane, therefore enabling the system to perceive obstacles that the planar view provided by a 2D LiDAR could not; this update will allow the user to navigate a range of more complex environments.

### Feedback and Actuation Interface

We represent the virtual world as a scaled-down model presented virtually in front of the user. The prototype system uses a set of three wire spools mounted around the user's body to provide force feedback (Figure 4). Similar devices have been used to provide feedback based on torque [2]. The wires from each of these spools meet at a handle, which the user holds. By keeping the wires taut, and measuring the length of each wire, the system can triangulate the location of the user's hand. To exert forces, we apply additional tension to the wires, allowing us to create a force pointing anywhere

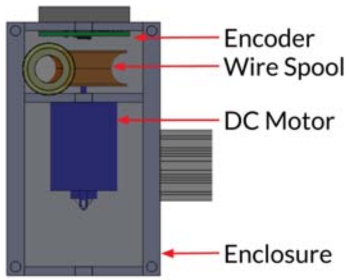



**Figure 4: Schematic of one of In-Sight's three wire spools.**

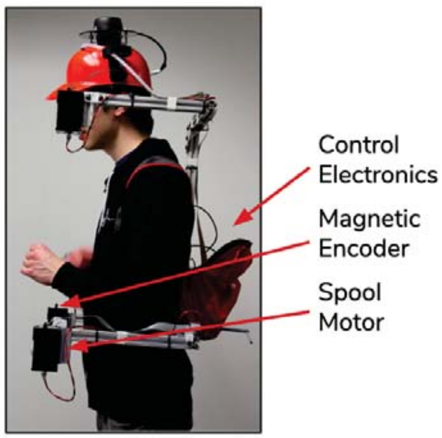



**Figure 5: Electronics subsystems in context.**

towards the user. We control the direction and intensity of this force to simulate touching a surface by making the force normal to a virtual surface when the user's hand touches it.

The wire length is measured by detecting the rotation of the spools using magnetic encoders (Figure 5). Both the constant force applied to the wires to keep them taut and the feedback force to the user are provided by DC motors with custom motor controllers. The maximum force each motor can apply to the wires is approximately 5N (1.12 pounds), though in regular use, the total force applied to the user by all three motors rarely exceeds 10N (2.25 pounds). A microcontroller, connected over USB to the controlling computer, tracks the position of the encoders and drives the motors.

While our initial prototype was generally effective at providing usable feedback, the system did experience a few problems, including torque ripple in the motors, unreliable spooling, and a low maximum feedback force. The new system has several improvements to address these problems. Most notably, replacing the DC motors with specially selected BLDC motors and a more sophisticated driver allows a system of similar size, weight, and power to produce a greater torque with less cogging.

## OPEN PROBLEMS

Haptic navigation devices present interesting challenges in improving mobility and spatial awareness for people who are blind. During the next iteration of In-Sight, we hope to gain a better understanding of the effect of force feedback on navigation.

When we model an environment, our primary concern is how to represent a constrained space in a way that is understandable to the end user. Lederman and Klatzky discuss whether haptic space perception is isotropic, i.e. if users of haptic interfaces can accurately judge distances [5]. If they cannot, are there ways to emphasize key features of the environment using this inherent anisotropy?

Another concern with non-visual communication is the rate that information can be presented to the user in a comprehensible form. The visual system provides an immense amount of spatial information, enabling independent navigation and wayfinding. Force-feedback devices currently provide information to a user only at a single point, and must therefore maximize the density of information provided by that point if they are to have any hope of emulating the capabilities of the visual system. Which aspects of the environment are the most useful for navigation, and how can these features be most efficiently represented?

One assumption behind our choice of force feedback is that if users understand the general layout of the space that they are in, they will be better able to effectively navigate through it. How does force feedback compare as a mode of communication about a space to other non-visual modes? In-Sight provides a way to learn more about the link between understanding a space and routing through it and contributes to the existing dialogue on the effect of haptics on localization, obstacle avoidance, and navigation.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## REFERENCES


[1] Dragan Ahmetovic, Cole Gleason, Kris M. Kitani, Hironobu Takagi, and Chieko Asakawa. 2016. NavCog: Turn-by-turn Smartphone Navigation Assistant for People with Visual Impairments or Blindness. In *Proceedings of the 13th Web for All Conference (W4A '16)*. ACM, New York, NY, USA, 9:1–9:2. https://doi.org/10.1145/2899475.2899509

[2] T. Amemiya and H. Gomi. 2013. Directional Torque Perception with Brief, Asymmetric Net Rotation of a Flywheel. *IEEE Transactions on Haptics* 6, 3 (July 2013), 370–375. https://doi.org/10.1109/TOH.2012.38

[3] P. Arcara, L. Di Stefano, S. Mattoccia, C. Melchiorri, and G. Vassura. 2000. Perception of depth information by means of a wire-actuated haptic interface. In *Proceedings 2000 ICRA. Millennium Conference. IEEE International Conference on Robotics and Automation. Symposia Proceedings (Cat. No.00CH37065)*, Vol. 4. 3443–3448 vol.4. https://doi.org/10.1109/ROBOT.2000.845258

[4] C. Bonivento, A. Eusebi, C. Melchiorri, M. Montanari, and G. Vassura. 1997. WireMan: a portable wire manipulator for touch-rendering of bas-relief virtual surfaces. In *8th International Conference on Advanced Robotics, 1997. ICAR '97. Proceedings*. 13–18. https://doi.org/10.1109/ICAR.1997.620155

[5] S. J. Lederman and R. L. Klatzky. 2009. Haptic perception: A tutorial. *Attention, Perception, & Psychophysics* 71, 7 (Oct. 2009), 1439–1459. https://doi.org/10.3758/APP.71.7.1439

[6] Jack M. Loomis, Reginald G. Golledge, and Roberta L. Klatzky. 1998. Navigation System for the Blind: Auditory Display Modes and Guidance. *Presence: Teleoperators and Virtual Environments* 7, 2 (April 1998), 193–203. https://doi.org/10.1162/105474698565677

[7] William R Mark, Scott C Randolph, Mark Finch, James M Van Verth, and Russell M Taylor Ii. [n. d.]. Adding Force Feedback to Graphics Systems: Issues and Solutions. ([n. d.]), 6.

[8] Margaret Minsky, Ouh-young Ming, Oliver Steele, Frederick P. Brooks, Jr., and Max Behensky. 1990. Feeling and Seeing: Issues in Force Display. In *Proceedings of the 1990 Symposium on Interactive 3D Graphics (I3D '90)*. ACM, New York, NY, USA, 235–241. https://doi.org/10.1145/91385.91451

[9] Jun Murayama, Laroussi Bougrila, Yanlinluo Katsuhito Akahane, Shoichi Hasegawa, BÃĺat Hirsbrunner, and Makoto Sato. 2004. SPIDAR G&G: A two-handed haptic interface for bimanual VR interaction. In *Proceedings of EuroHaptics 2004*. 138–146.

[10] K. Patil, Q. Jawadwala, and F. C. Shu. 2018. Design and Construction of Electronic Aid for Visually Impaired People. *IEEE Transactions on Human-Machine Systems* 48, 2 (April 2018), 172–182. https://doi.org/10.1109/THMS.2018.2799588

[11] C. Ramer, C. Ziegler, S. ReitelshÃűfer, and J. Franke. 2014. Sensor-guided jogging for visually impaired. 467–472. https://doi.org/10.1109/BIOROB.2014.6913821

[12] Daisuke Sato, Uran Oh, Kakuya Naito, Hironobu Takagi, Kris Kitani, and Chieko Asakawa. 2017. NavCog3: An Evaluation of a Smartphone-Based Blind Indoor Navigation Assistant with Semantic Features in a Large-Scale Environment. In *Proceedings of the 19th International ACM SIGACCESS Conference on Computers and Accessibility - ASSETS '17*. ACM Press, Baltimore, Maryland, USA, 270–279. https://doi.org/10.1145/3132525.3132535

[13] Spidar Makoto Sato and Makoto Sato. 2002. *Development of String-based Force Display:*.

[14] R. Velazquez, E. Fontaine, and E. Pissaloux. 2006. Coding the Environment in Tactile Maps for Real-Time Guidance of the Visually Impaired. In *2006 IEEE International Symposium on MicroNanoMechanical and Human Science*. 1–6. https://doi.org/10.1109/MHS.2006.320235