Toward an Open Platform of Blind Navigation via Interactions with Autonomous Robots

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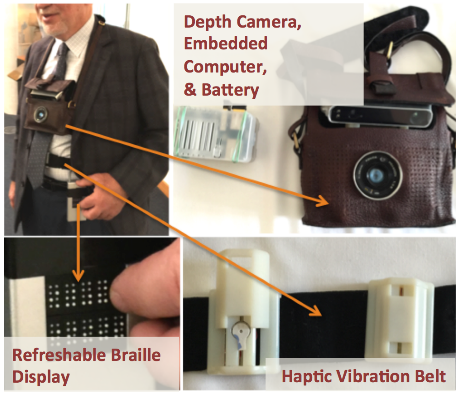

Figure 1: Wearable Vision System in [13]

ABSTRACT

Recent advances in autonomous robotics, such as technology developed for self-driving vehicles, have demonstrated their impact in facilitating travel from point A to B, and may potentially assist independent navigation for blind and visually impaired people. Our previous and ongoing work using wearable vision and guiding robots integrates assistive haptic feedback [5, 8, 13] with existing navigation aids, e.g. canes and guide dogs. However, reproducing and extending this early work for further development and safe testing remains a challenge. To this end, we introduce open and reproducible hardware and software development protocols, some of which have already been adopted in university courses as well as research or robotic competitions. To validate the safety and effectiveness of assistive technology solutions, we encourage the spread of reproducible materials and standards to the wider community, including university educators, researchers, governments, and, most importantly, users who are blind and visually impaired.

KEYWORDS

Blind Navigation; Guiding Robot; Trail Following; Wearable Vision; Haptic Devices

INTRODUCTION

The World Health Organization estimates that approximately 286 million people worldwide are blind or visually impaired (BVI) [3]. In the absence of sufficient visual information, the essential task of navigating from point A to B in dynamic, cluttered, or unfamiliar environments remains a challenge to perform without collisions for BVI people using the most common mobility aids, i.e. white canes and guide dogs. For example, cane users naturally explore their immediate surroundings with physical cane contacts, but in many situations it is desirable to avoid contacts if possible, e.g. while navigating among crowds of pedestrians. Recent work has applied onboard computer vision for safe navigation in indoor and outdoor scenarios. The systems typically include sensors, computing units, and feedback components, providing either global localization [9], local obstacle detection/avoidance [6], or both [7, 8, 11, 12].

WEARABLES

Our recent work [2, 5, 10, 13] presented carefully designed wearables consisting of three stages: perception, planning, and human-robot interaction (Figure 3). We note that the functional requirements of these stages can be met with many sensors and extensive computation on autonomous robots. However, wearables necessitate tradeoffs between sensing, computation, and system usability. For

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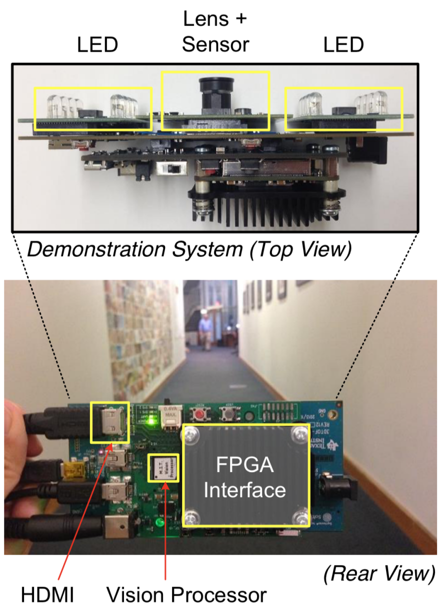

Figure 2: Low-power vision processor designed in [10]

daily use, compactness and acceptable battery life require minimizing size and power consumption, imposing challenging constraints on available hardware and algorithms. Additionally, non-visual interfaces require sophisticated design for effective and timely user feedback.

Wearable Vision

The wearable systems estimate local world states and segment point-cloud data into free space and obstacles and their corresponding distances to the user. This computation was implemented in a low-power 3D vision processing chip (Figure 2), enabling a blind user to avoid unexpected collisions while walking through complex environments such as mazes or hallways. We further built a system that uses depth information from a wearable camera to provide on-board object detection in real time. The ability to recognize and localize several types of objects (for example, an empty chair vs. occupied chairs) facilitates completion of these tasks more accurately than using the cane alone. The chair-finding task is a representative example of a general object-detection task.

Haptics and Non-Visual Feedback Interfaces

Interactions between a BVI user and a wearable vision system are mediated through haptic feedback or a braille display. Unobtrusive haptic feedback is designed to provide a user with enough information to navigate toward a goal collision-free without overwhelming them with extraneous sensory input.

The haptic array consists of five motors mounted on an elastic belt worn around the chest or abdomen. The motors, mounted at intervals of at least 10 cm, generate pulses of variable strength and frequency, representing directions and distances to obstacles. A vibration signal progressing from weak to prominent indicates an approaching obstacle, whereas the absence of vibration indicates free (navigable) space. In the chair-finding task, the front vibrating motor indicated the proximity of either the chair or another obstacle. The left or right motors were more selective, vibrating only when an empty chair was detected. With these settings, the maximum amount of information sent to a user was 15 bits per second: three signaled directions triggered at a rate of five frames per second.

The refreshable braille display (Metec AG, Stuttgart, Germany) contains 10 8-pin braille cells, arrayed in 2 rows of 5. For object recognition, we encoded four different object types using one braille symbol per object type: *o* for obstacle, *c* for chair, *t* for table, and *a* space for free space. The first (top) row of cells encodes distances greater than $1m$, and the second (bottom) row encodes distances below $1m$. Our tests suggest that a haptic array provides less information but shorter latency than a braille display, suggesting that a haptic array is more suitable for collision avoidance while the braille display is better for object detection and identification tasks. We did not implement auditory feedback because the sounds may interfere with BVI people's capacity to process relevant environmental sounds such as voices, traffic, walking, etc.

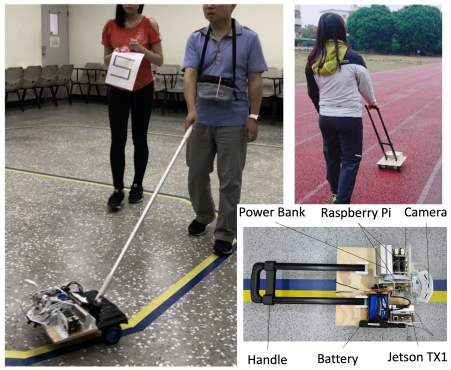

Figure 3: The proposed robotic guide dog.

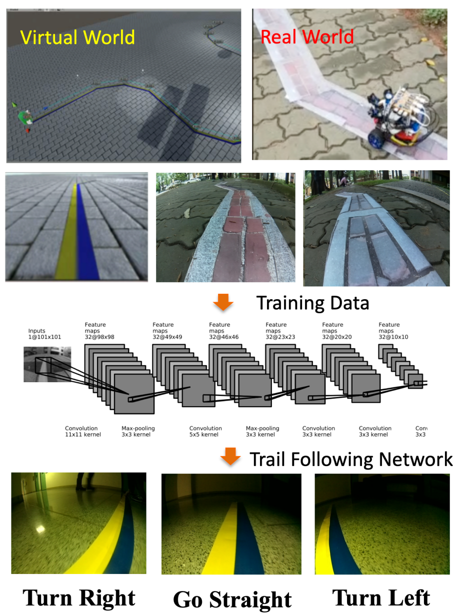

Figure 4: A deep convolutional neural network was trained by virtual and real-world data.

GUIDING ROBOTS

Although wearable vision and haptic feedback systems are designed to complement a traveler's white cane, it remains challenging to reliably manage physical contacts between a BVI user and the environments. A robotic guide may serve as an alternative to another common mobility aid: guide dogs. The total cost of training and acquiring a guide dog is currently extremely high, sometimes exceeding $50k, excluding costs of ongoing care. Moreover, it may take 2 years in total to raise a guide dog from a new born puppy to a well trained trustworthy partner. In contrast, a user may find it intuitive to follow a guiding robot behaving similarly to a service animal and extending the range of reliable navigation. Robot guides become affordable for most BVI users in the near future, and the production time is as short as every other off-the-shelf commercial robots.

Sensing and Computation for Autonomous Robots

We wish to develop a guiding robot to autonomously follow various man-made trails for BVI people in pedestrian environments; the hardware design is shown in Figure 3. We propose to learn the robot states (robot's heading and lateral distance from the trail) and actions (go straight, turn left or right) mapping from camera inputs. The settings of 3 cameras on the "training" robots make it easier to collect 3 different observations of headings (center and 45 degrees to the left or right) simultaneously for training data. While the "testing" robot only uses the camera in the center front, the images from the "training" robot's center camera indicates that the robot is heading the center, thus the robot should keep going straight. The images from the left of the three camera indicates that the heading is 45 degrees to the left, thus the robot should turn right at the moment, and vice versa. Deep trail-following models were trained using data from real-world and virtual environments, which are robust for various background textures, illumination variances, and interclass variations. (Figure 3). We implemented two autonomous vehicle paradigms in [4]: one to map an image into a robot action, and the other use an image to predict some meaningful information, i.e. the affordance of road situations: lateral distance from road center, heading, etc. Such outputs can then be processed by a human, potentially BVI users to decide the coming control strategies and robot actions.

Human-Robot Interfaces

During the prototyping we tried 1) a leash, 2) a harness with suitcase handle, and 3) cane-like rod. We found the leash to be less intuitive for providing directional feedback than a handle or rod. We then experimented with the cane-like rod and two hand grasps (Figure 4). Similar to using a white cane, the forehand gesture allows the user to explore the surrounding environment with the rod extended. The user could also hold the rod upright in a crowded scenario. Nevertheless, we did not find significant

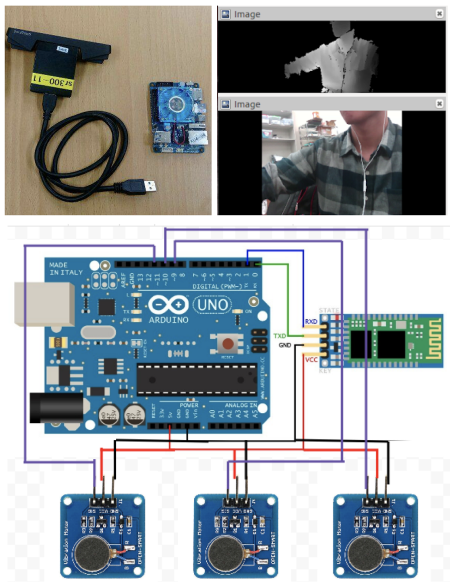

Figure 5: Open Materials

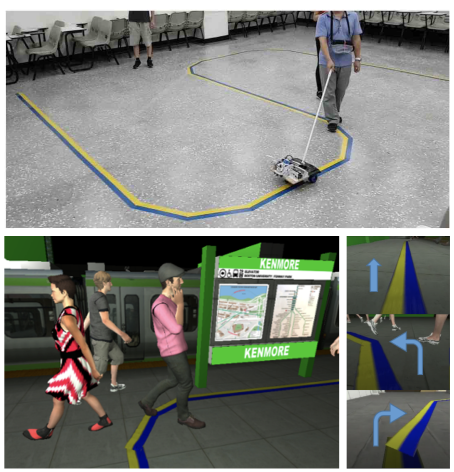

Figure 6: Safe testbeds.

differences between hand grasps. Further experiments are needed to evaluate the usefulness of a harness handle.

DISCUSSIONS FOR OPEN CHALLENGES

Reproducible Open Hardware and Software

Although assistive technologies for blind navigation have been researched for decades, very few have been reproduced or further developed as products. Making open reproducible hardware and software is a way to push forward progress and validate the robustness of the technologies. We have made efforts to develop open teaching materials in university courses. The course is an interdisciplinary, project-based course in which small teams of students work on the human-centric topics to design a device, piece of equipment, app, or other solution. Over the course of the term, each team iterates through multiple prototypes and learns about the challenges and realities of designing assistive technologies for people with disabilities. The course is inspired by the MIT PPAT (6.811: Principles and Practice of Assistive Technology) course initiated by Prof. Seth Teller [1]. The hands-on modules are available at https://openppat.github.io/.

Safe, Realistic, and Controlled User Studies

User studies are critical to advancing the development of blind navigation technologies. A persistent challenge has been the balance between experimental control, ecological validity, and safety. Some tests with BVI community have already carried on and reported in [5, 13], but we could expect more need to be implemented in the future. We hope the cross-disciplinary community can build and share qualified testing sites, provide experiment protocols, and evaluate the robustness of the developed works in the near future.

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