Tactile Feedback on Flat Surfaces for the Visually Impaired

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CHI'12, May 5–10, 2012, Austin, Texas, USA.
ACM 978-1-4503-1016-1/12/05.

Abstract
In this paper we introduce a mobile, generic, and inexpensive visuo-tactile sensory substitution device for the visually impaired. The device helps users to explore the world around them, by pointing it towards objects of the environment and rendering tactile information to the objects sensed by a camera. With the help of two visually impaired participants, we conducted three preliminary experiments and evaluated the performance of the device in detecting, reaching and exploring tasks. Both participants were able to detect, explore and reach for a given object of interest in a controlled room setting using only the tactile information rendered on the flat panel of the device. The implication of results and future directions for tactile assistive devices are discussed.

Keywords
assistive devices; sensory substitution; tactile feedback.

ACM Classification Keywords
H.5.2 [Information Interfaces And Presentation]: User Interfaces - Haptic I/O. K.4.2 [Social Issues]: Assistive Technologies For Persons With Disabilities.

General Terms
Design.

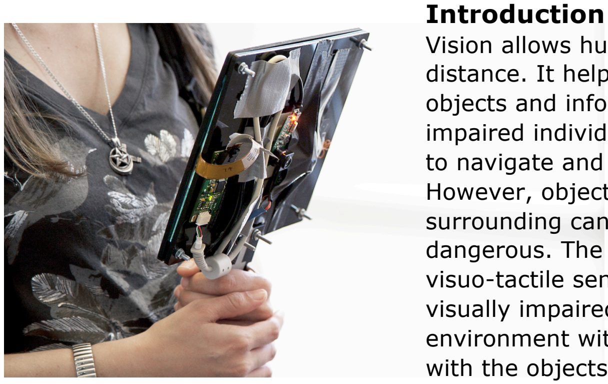

figure 1. A user holding the tactile assistive device.

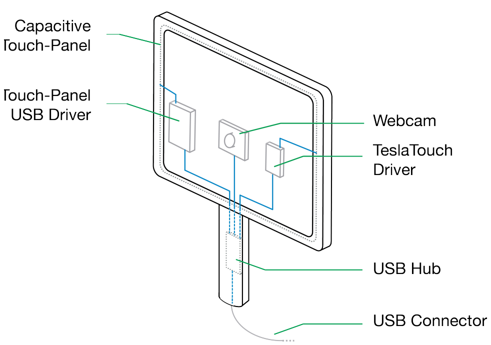

figure 2. The proposed assistive device with its components labeled.

Introduction

Vision allows humans to experience the world at a distance. It helps to detect remote and unreachable objects and informs us about physical features. Visually impaired individuals rely heavily on their sense of touch to navigate and interact with their environment. However, objects might be out of reach, and the surrounding can be cluttered and sometimes harmful or dangerous. The goal of this research is to develop a visuo-tactile sensory substitution system that allows visually impaired individuals to explore their environment without registering a voluntary contact with the objects.

A wide variety of commercially available assistive devices aim to extend their users' reach and help them to explore their environments. These devices range from the universally adopted white cane to speech-enabled GPS devices and ultrasound radar. However, their use is limited to specific applications. While many devices assist in a user's outdoor navigation or obstacle detection, only a few help them in tasks as elementary as searching for a cup on a kitchen table or helping to locate a misplaced trashcan in a room.

We are interested in enabling the visually impaired to explore their environment at a distance, detect objects of interest, and reach for them. In this paper, we propose a mobile, generic, and inexpensive device that maps live and dynamic visual information acquired through a camera to tactile feedback displayed on a panel. It provides a wide range of tactile sensations to the user's fingers by means of the TeslaTouch technology [3], thus taking advantage of the sensitivity of the finger pads.

With the help of two visually impaired participants, we evaluated the effectiveness of tactile feedback presented through our device. The goal of these preliminary experiments was to determine if visually impaired users could explore, detect and reach for objects based only on tactile feedback presented on the flat surface of the device. In particular, we are interested in the participants' abilities to interpret the mapping between tactile information provided on the 2D screen and the real world.

The organization of this paper is as follows: After first presenting the related work, we describe the design of our device. Then, we present three evaluation experiments followed by discussion and future work.

Related Work

A wide range of commercial devices exists to aid the visually impaired in everyday tasks, mainly to help them in reading and navigation tasks.

As early as the 70's, the Mowat sonar sensor helped to extend the reach of a user by sensing proximate objects and displaying them through vibrations on the hand. More recently, a similar device by Iannacci et al. [4] used laser-based sensing and computer vision for environment sensing, and additionally utilized multiple vibrators to provide haptics feedback. These devices are mainly used for obstacle detection, and their vibratory output provides only a limited amount of information about the environment.

Another class of devices maps visual information acquired with a camera to actuator arrays. For example, TVSS [1] translates live images to a tactile grid mounted on the back of a chair. Although these devices provide spatial haptic-feedback using vibrator grids, they do not take advantage of the high sensitivity of the hand or fingers pads. More recently, Bach-y-Rita et al. [2] adopted a similar approach on the sensitive tongue using electrical impulses. This approach uses a higher resolution tactile display but may be uncomfortable, socially awkward and cumbersome since the device has to be placed in the mouth.

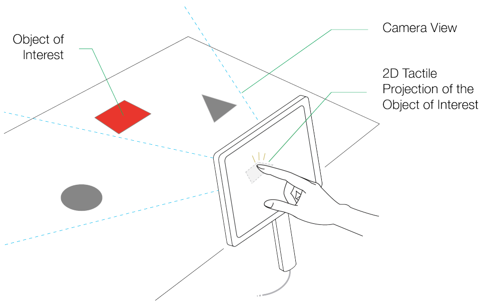

figure 3. 2D projections of the object of interest are mapped to tactile sensations on the flat panel of the device.

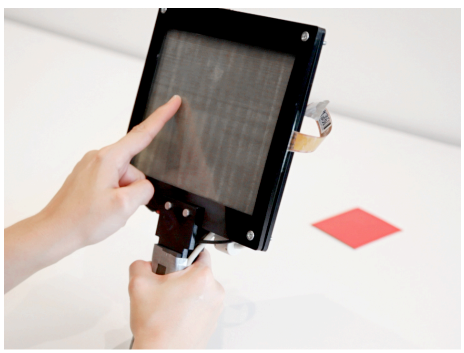

figure 4. A participant performing Experiments 1 and 2.

Many devices exploit the fine tactile resolution of human fingers, mainly in braille-like reading devices. Pin-array-based reading aids are common in today's market, although fewer visually impaired are now learning to read braille [8]. The Optacon [5] device aims to translate visual information to tactile sensation by scanning text and translating it into vibratory patterns on the fingerpad. Pin displays are difficult to implement, mechanically complex and are expensive.

Xu et al. [9] investigated the perception of shape features using TeslaTouch. TeslaTouch provides a wide range of tactile sensation using electrovibrations - such as vibration, friction and texture - without moving any part of the touch surface [3]. We extended their work to help visually impaired users explore their environment based on rich tactile information.

Prototype Device Design

The proposed assistive device consists of a surface-capacitive touch-panel, a camera attached on the back, and a TeslaTouch hardware driver (Fig. 2) housed in a hand mirror-shaped acrylic casing. The users comfortably hold the device with one hand while sliding their fingers on the screen. The current device consists of off-the-shelf components and weighs 750 grams. The size of the touch surface is 13 cm by 18 cm.

The camera senses remote objects in the environment and projects them on the touch surface (Fig. 3). When the user touches the 2D projection of the object on the screen, control signals are sent to the TeslaTouch hardware, rendering appropriate tactile sensations, and thus informing the user of the object's presence. All components are connected to a notebook via USB.

Simple computer-vision software detects an object of interest based on detecting its color. The color of an object is registered and used as a reference for detection. Multiple vision-based sensing strategies could be employed to identify an object, including feature-based recognition [6], depth sensing and RFID technology [7]. In this paper, we are interested in insuring that visually impaired users are able to explore, detect and reach for objects based on the tactile feedback, without utilizing comprehensive computer vision techniques. The next section presents evaluation experiments of the device in an indoor setting.

Preliminary Experiments

Before the experiments, we conducted a fifteen-minute interview session during which participants reported their present age, type, cause and degree of blindness; the age at which the blindness occurred; their use of technologies such as computers, email, games, etc.; and their preferred assistive devices if they use any. After the interview, the experimenter verbally read through the consent form highlighting the participant's rights to terminate participation at any time. They signed consent forms before starting the experiments.

Participants

Two legally blind female participants (69 and 30 years old) evaluated the device. S1 was born blind while S2 had limited vision through the left eye. S2 could detect shades of objects up to 10 feet but could not accurately discriminate among colors, shapes, faces and textures. Both participants used a cane and were familiar with assistive devices such as JAWS screen-reading software, Optacon, braille watches and signature guides. Other than vision, both participants could hear and feel normally with no motor impairment.

General Procedures

The procedures for all three experiments were similar. The experiments were performed in an empty room, 15 feet 6 inches wide by 13 feet 4 inches deep. Participants held the prototype tactile device with one

figure 5. A visually impaired participant performing Experiments 3 in a controlled room setting.

hand and scanned the room by sliding the index finger of the other hand on the touch screen. In all of the experiments, we provide a prominent and uniform tactile feedback mapped to the detected object based on the perception data presented in Bau et al. [3].

The instructions and tasks were verbally explained to the participants before the start of each experiment. Participants completed a small training session to familiarize themselves with the device, haptic feedback and tasks of the experiments, and were allowed to rest between trials.

Experiment 1: detecting the object

The goal of Experiment 1 was to test if participants could detect the presence of an object placed in front of them using the proposed assistive device.

PROCEDURES

Participants sat on a chair in front of an empty white table. The device was clamped to the table to ensure that the camera was always covering the same area of the table. A square red piece of wood was used as an object. Each participant was tested in 40 trials. During half of the trials, the object was placed in a random location in front of the device. During the other half of the trials, no object was placed on the table. Trials with or without the object were also randomized in order. The task for the participant was to report whether they felt the presence of the object or not. In the cases where an object was detected, they also pointed to its location on the touch screen. Participants' response and trials times were recorded.

RESULTS

S1 scored all correct while S2 made one mistake, suggesting that the detection task was fairly simple and straightforward for the participants. On average, participants spent significantly less time actually detecting the object (7 seconds) than when no object was present (10 seconds). A paired T-test on the completion times of each trial indicated this inference; $t(39)=4.9$; $p<0.001$. Ten seconds corresponds to the average time the participants spent exploring the whole surface of the device when the object was not present.

Experiment 2: detecting, reaching and lifting the object

In this experiment, we investigated if participants could perform the task of detecting, reaching for and picking up the object. We were interested in determining if participants were able to transition between the screen space used for object detection and the real world.

PROCEDURE

The setup for Experiment 2 was identical to Experiment 1, except that participants could freely move the device during the task. Participants were instructed to detect the object on the flat panel and pick it up once they felt they were close enough to the object. Participants completed a few training trials to become familiar with the task, including understanding how the location of tactile feedback changes depending on the distance and the orientation of the device with respect to the object.

Each participant was tested in ten trials. The same red square was placed at random locations on the table in every trial. Once the participant lifted the square, the trial was stopped and the time was recorded.

RESULTS

Both participants completed each trial within a predefined 3-minute limit. Average completion time for S1 was 16.9 seconds, and for S2 it was 45.6 seconds. S2's data suggest a prominent learning curve. The average time of the final 5 trials was reduced to 28 seconds. The results suggest that participants were able to quickly learn the mapping between the screen and the real world, i.e., interpreting the tactile information provided in order to reach the object.

Experiment 3: finding the trashcan

In Experiment 2, participants were executing trials while sitting in front of a table. The goal of Experiment 3 was to test whether participants were able to locate and reach for an object in a room. Participants' mobility was thus less constrained, and they were able to move freely in the room.

PROCEDURES

The task consisted of finding a blue recycling bin in the room and dropping a ball in it. This bin was placed randomly along one of the walls of the room. Another bin, a "distractor" of the same size, but black in color, was also placed in the room to create confusion for the participants. Each trial started with participants standing in the middle of the room.

We compared the performance of participants using the proposed device with their usual method of finding the bin, i.e., using walls and their cane as guidance. Participants first completed seven trials using their conventional way of finding the bin in the room, followed by seven trials using the device. Only the blue bin was mapped to tactile feedback. The notebook computer was placed in a backpack, which participants carried around with them.

Once participants felt they were close to the bin, they dropped a ball inside the bin. If they dropped the ball in the recycling bin then it was recorded as a success. The trial was completed and trial time was recorded. If they dropped the ball in the distractor bin, it was recorded as a false alarm, and they were notified of the mistake and asked to continue the trial until they found the right bin.

RESULTS

Analysis of the recorded data showed that participants were able to find the recycling trash bin within the 5-minute limit using either the conventional or the device-based technique. The average completion time using the proposed assistive device was 42 seconds, which was not statistically different from the average completion time of 37 seconds using conventional methods [paired T-test: $t(13)=0.69$, $p=0.5$]. However, participants made far more mistakes when they used the conventional method (10) compared to the device-based method (1).

Participants used differing strategies when performing the task without tactile feedback, both leading to multiple errors (4 and 6 for S1 and S2, respectively). S1 walked towards one wall and moved along the wall until she hit a trash bin. S2 detected what she perceived was the bin with her limited vision and went towards it. She could not distinguish between the blue trash bin and the black one and was confused by shadows and other visual artifacts. Although the difference in completion times with and without tactile feedback was not statistically significant, these results suggest that tactile feedback helped participants in preventing errors when looking for the correct object.

DISCUSSION AND FUTURE WORK

In this paper, we presented three experiments in which visually impaired participants completed detection and reaching tasks using a mobile tactile feedback device. The purpose of these experiments was to evaluate the efficiency of the device in simple tasks and determine whether participants could interpret the dynamic and real-time tactile information displayed on its screen. In all three experiments, participants successfully completed tasks fairly quickly with few, if any, errors.

Participants were able to use the mapping between the 2D spatial tactile feedback and 3D objects placed in the real world without undergoing extensive training with the device. While participants were asked to perform a fairly simple task, these results are encouraging since a common drawback of assistive devices is that they require a long training period [1, 2, 5].

Tasks presented in the paper utilized a simple color extracting technique to display a feature of the surrounding object in a controlled setting. However, the limitation of the device and technology is not limited to only color detection and 1-bit tactile rendering. Currently, we are exploring optimal strategies to extract a wide range of features, such as edges, contours, contrasts, etc., and present them using tactile sense. Our goal is to develop a set of vision to tactile mappings that could be affective in complex real life settings, and assist impaired individuals in daily basis.

The prototype presented used off-the-shelf components to provide rich tactile feedback. Some of these components are heavy and have unnecessary features and can be replaced by less expensive elements. For example, the costly ITO-based transparent electrode used in our current touch-panel can be replaced by a less costly and lighter opaque alternative. This gives our device a competitive advantage with respect to other high-resolution haptic devices whose cost is usually dictated by complicated design and complex control mechanisms. In addition, the device could be easily adapted to use the camera and computational resources of mobile devices.

In addition to the tasks addressed in the paper, the proposed device can be used in applications beyond those of obstacle detection, navigation aid or reading assistance. For example, one could imagine it mapping tactile sensations to photographs, symbols or even weather conditions. By pointing the device towards the sky, a user could differentiate a clear sky from scattered clouds. It could potentially be used with few, if any, hardware modifications to map tactile information to visual content provided by other input streams, such as pictures from a USB key or maps from the internet.

The proposed device opens a wide range of applications and directions for future research. We plan to extend our detection mechanism to a broad range of objects using a database of objects of interest, e.g., car keys, coffee mug, etc. We will explore how to provide a wider range of information through tactile feedback and to map tactile sensations to object features and spatial cues.

References

[1] Bach-Y-Rita, P., Collins, C. C., Saunders, F. A., White, B. and Scadden, L. Vision Substitution by Tactile Image Projection. Nature, 1969, 221 (5184). pp. 963-964.

[2] Bach-y-Rita, P. and Kercel, S. W. Sensory substitution and the human-machine interface. Trends in Cognitive Sciences, 2003, 7 pp. 541-546.

[3] Bau, O., Poupyrev, I., Israr, A. and Harrison, C. TeslaTouch: electrovibration for touch surfaces. Proc. of UIST, 2010. ACM. pp. 283-292.

[4] Iannacci, F., Turnquist, E., Avrahami, D. and Patel, S. N. The haptic laser: multi-sensation tactile feedback for at-a-distance physical space perception and interaction. Proc. of CHI, 2011. ACM. pp. 2047-2050.

[5] Linvill, J. G. and Bliss, J. C. A direct translation reading aid for the blind. Proceedings of the IEEE, 1966, 54 (1). pp. 40-51.

[6] Lowe, D. G. Object Recognition from Local Scale-Invariant Features. Proc. of International Conference on Computer Vision, 1999. IEEE pp. 1150.

[7] McDaniel, T. L., Kahol, K., Villanueva, D. and Panchanathan, S. Integration of RFID and computer vision for remote object perception for individuals who are blind. Proc. of Ambi-Sys workshop, 2008. pp. 1-10.

[8] MSNBC. Fewer blind Americans learning to use Braille. 2009.

[9] Xu, C., Israr, A., Poupyrev, I., Bau, O. and Harrison, C. Tactile display for the visually impaired using TeslaTouch. Proc. Of CHI, 2011. ACM. pp. 317-322.