Kin'touch: understanding how visually impaired people explore tactile maps

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Kin' touch: Understanding How Visually Impaired People Explore Tactile Maps

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Abstract

Tactile or interactive maps are largely used as an orientation aid for visually impaired people. Yet, little is known about haptic exploration strategies and their influence on the resultant cognitive mapping. We have designed a prototype with the potential to automatically analyze different users' exploration strategies. This prototype integrates data from the MS Kinect camera and a multi-touch table. It registers location of hands and digits on a tactile map. Results of preliminary studies show that this approach is promising.

Keywords

visual impairment; depth cameras; kinect; multi-touch; fusion; finger tracking; haptic exploration; tactile maps

ACM Classification Keywords

K.4.2. [Computers and Society]: Social Issues - Assistive Technologies for Persons with Disabilities; H.5.2. [Information Interfaces and Presentation]: User Interfaces; I.4.9. [Image Processing and Computer Vision]: Applications; J.4 [Social and Behavioral Sciences]: Psychology

Motivation for the design

With 285 million people being visually impaired around the world [14], making information accessible to the visually impaired is a fundamental challenge. Raised-line pictures play an important role as they present

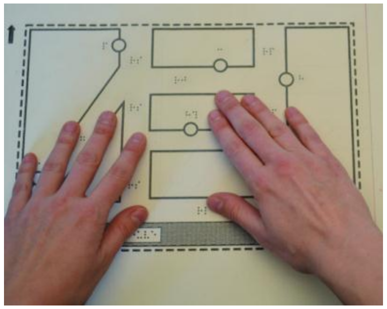

Figure 1: Exploring a tactile map

information in an accessible format. They are, for example, used to present maps in geography (figure 1) or geometric figures in mathematics. Interactive maps are produced by placing a raised-line map on top of a touch-screen which facilitates the communication of additional audio information (e.g. street names) [1].

A precise description of strategies used by visually impaired subjects while exploring maps would enable progress in three important areas: (1) the design of the map - the exploration description may help to identify and solve specific problems with the map itself (e.g., ambiguous lines or symbols); (2) the design of the interaction techniques - exploration strategies may highlight preferences for interacting with the map (e.g., role of the different digits); (3) the inference of guidelines on how to teach map exploration.

Several studies in experimental psychology have investigated haptic exploration strategies of tactile pictures in visually impaired and sighted subjects [6,12]. The observed exploration strategies included the use of only one finger (index), or that of multiple fingers. When exploration is bimanual, subjects may use one hand as a stationery reference point or move both hands simultaneously. The precise nature of these exploratory modes and their relations to performance level remain obscure [11] and need further investigation. Furthermore, the study of exploration strategies in psychology usually relies on video observation, which is time-consuming.

Our project was to design a system to better capture the users' hand motions on a tactile map. This system was designed to speed up the analysis of exploration strategies by automatically tracking and identifying the fingers used to explore the surface. To date, many projects have focused on finger tracking. The majority were based on automatic recognition in video, tracking either bare hands [4] or markers [8]. More recently depth sensors have been used [5, 13]. Other projects used optical multi-touch surfaces for finger tracking and identification [3]. To our knowledge no prior project investigated the automatic analysis of exploration strategies of tactile images by visually impaired people.

Concept

Our interactive map prototype [1] uses a 3M projected capacitive multi-touch screen M2256PW. This device was selected as its technology is compatible with placing a map on its surface (unlike an optical table). It is possible to obtain coordinates of ten or more simultaneous finger positions on the screen with a precision of 0.28 mm. However it has two important limitations. Firstly, it can only track the position of fingers that actually touch the surface. The goal is to also track fingers above the surface so that all finger movements are monitored. Secondly, the multi-touch table cannot identify which hand (left or right) and which finger (i.e. the thumb, index, etc.) caused the touch. A new identifier is created for each touch event, even if the same finger made two successive touches. Furthermore, it is not possible to determine whether the touch event is provoked by a finger or another body part, such as the palm of the hand. These unexpected touch events are considered as false positives.

To overcome these limitations, we relied on the rationale proposed by Wilson [13]: First of all, it is possible to use the Kinect [7] to detect finger positions; secondly, fingers are detected even if the surface is not flat (i.e. the relief of the tactile map does not disrupt

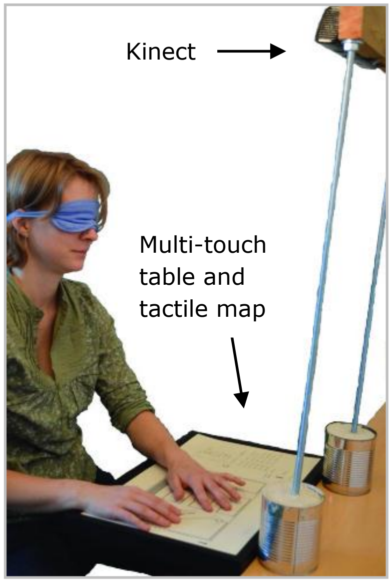

Figure 2: Prototype for Kinect and multi-touch fusion

detection); and finally, it is possible to get information about body parts above the surface. However the precision of the Kinect as a depth sensor is inferior to the precision of a touch surface [13]. Therefore we decided to merge finger detections from the Kinect with touch events from the multi-touch screen. The aim was to get precise information regarding hands and fingers involved during a complex exploration of a tactile map.

Prototype

Hardware and software architecture

Our prototype (figure 2) consisted of a multi-touch screen in horizontal position, a tactile map, a Kinect camera fixed above the touchscreen at 70 cm height and turned in the direction of the touch screen, and a computer connected to touch screen and Kinect.

The software consisted of two applications: one for detecting finger positions on the touch screen and a second for finger tracking in the Kinect image. The data was sent via the ivy middleware [2] to a log file. Each touch event contained a timestamp and x and y coordinates. The Kinect output contained the name of the finger (thumb, etc.) and corresponding hand (right or left), x and y coordinates of the finger and a timestamp. A third application called "fusion" (used for offline processing) read this data and created another output file that contained the name of the fingers and corresponding hand, x and y coordinates of the fingers, whether the fingers were in touch, and a timestamp.

Finger tracking algorithms

As the Kinect possesses two cameras (depth and RGB), it was easy to implement and compare two different algorithms within the same setup. Both algorithms use OpenCV functions [9] and OpenNI middleware [10].

VARIANT 1: USING DEPTH CAMERA

This algorithm uses the depth image (figure 3). The calibration phase consisted of two steps. First, a depth mask was created to segregate objects (i.e. hands and digits) from the background (i.e. the tactile map). Second, the user held their hand horizontally with the fingers spread. Angles between fingers were automatically measured. They were then used as additional constraints on finger identification. After calibration the noise was reduced and the image was converted into a binary image. Contours were detected as lists of points. Each contour was reduced to the minimum number of points needed to form the outline of the hand. Vertexes of the contour represented fingertips. Fingers were identified using previous finger positions and angles between fingers.

VARIANT 2: USING RGB CAMERA

The second algorithm identified fingers in the RGB image by using color markers (figure 4); two colors applied to alternating fingers were sufficient. The image was then transformed into HSV colors to eliminate any problems caused by lighting. During calibration the experimenter would click on the two colors in the image which enabled the algorithm to identify fingers by color tracking as well as angles and last finger positions. Although it required additional preparation before the experiment (adjusting color markers took 5 minutes), this algorithm was more stable for finger detection.

Fusion

The aim of the fusion was to combine and correlate touch data obtained from the multi-touch surface (touch events) with the data from the tracking algorithm (finger detections). For each touch event, the algorithm searched for the closest finger detection.

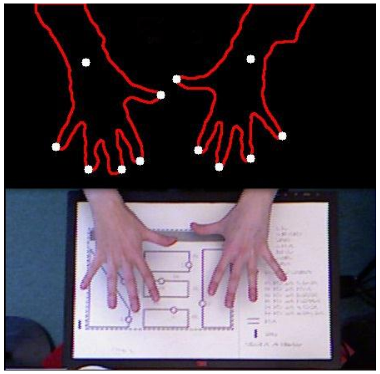

Figure 3: using depth camera

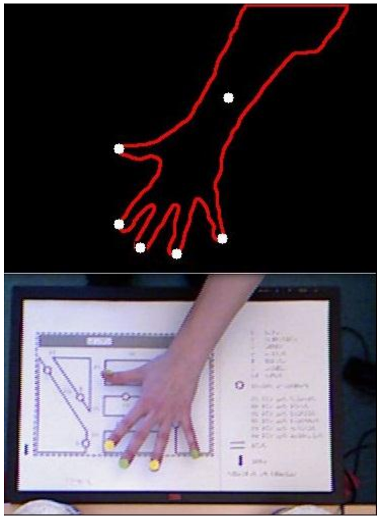

Figure 4: using RGB camera

Finger detections that had not been matched to touch events were considered as fingers above the surface. Touch events that did not correspond to finger detections were considered as false positives.

Temporal accuracy is important for fusion. Touch events were produced at 100 Hz; finger detections and fusion output at 10 Hz. As for spatial accuracy, the precision of finger detections was about 1.4 mm/pixel. This was precise enough to determine the average positions of the fingertips. The precision of touch events was 0.28 mm. Coordinates were transformed from the Kinect frame (640 x 480 pixels) to the multi-touch frame (1680 x 1050 pixels) for the fusion. The average position error after conversion was about 5.6 mm or 20 pixels. Although this accuracy seemed quite low, we validated during the preliminary tests that it was sufficient to match positions of the same finger from the multi-touch screen and the Kinect.

In brief, the fusion assigned the name of the finger to touch events, added position information about fingers not in touch with the surface, and eliminated false positive touch events. We implemented an offline fusion process as there was no need to analyze exploration strategies at runtime. The application read log files, executed the fusion process, and produced an output file with the results. As the output file format was the same for both variants of the finger tracking algorithm, the fusion process worked with either one.

Case studies

We did preliminary tests with both algorithms and offline fusion. Two aspects were important to us:
(1) Although it has been proven that cameras can be used for finger tracking in touch sensors [5,13], we wanted to check that those algorithms were adapted to finger tracking during exploration of a tactile image.
(2) We wanted to get concrete fusion results (i.e. success rate of the fusion, usage of different fingers, etc.) in order to decide if this approach could be used for analyzing haptic exploration strategies.

The test subject group consisted of three blindfolded (2 female, 1 male) and three legally blind (1 female, 2 male) participants. Participants possessed different levels of expertise in tactile map exploration based on the assumption that this factor impacts on exploration strategies. Two of the blind participants had significant expertise in map reading, whereas the third blind and the blindfolded participants had little expertise. We prepared a simple tactile map that contained six streets, six buildings, six points of interests and a river. For each test, participants were asked to explore the map in the way they normally do, or in the way that feels natural.

Using depth camera

The depth camera based algorithm proved efficient with most of the subjects: fingers were successfully detected and identified. Obviously, occluded fingers were not detected. Yet, the occlusion of some fingers did not hinder the correct identification of the remaining fingers (figure 5). Reappearing fingers were identified within one video frame. However the algorithm failed with one blind subject with good expertise in map reading. As a part of his exploration strategy, he frequently closed his fingers so they were no longer sufficiently separated (figure 6). Hence, the algorithm is globally working, but does not support every user's exploration strategies.

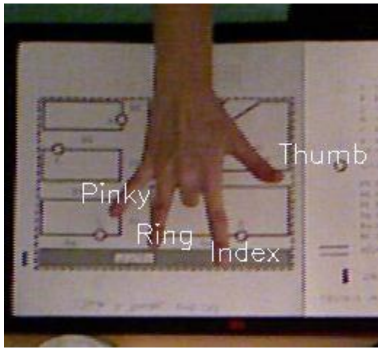

Figure 5: detection is working even when some fingers are occluded

Figure 6: when fingers are closed separation of fingers in the depth image is not possible

Using RGB camera
Color markers were placed on the fingers before map exploration. We observed that detection was stable for all users and that their choice of exploration strategy did not interfere with the algorithm. It proved efficient when the fingers were spread out as well as when they were closed. It did not depend on the number of fingers involved. Occlusion of certain fingers did not hinder the correct identification of remaining fingers. Reappearing fingers were identified within one video frame. The only negative was that wearing a watch led to reflections that were sometimes detected as color markers.

Fusion
Based on these preliminary results, we selected the RGB-image based algorithm for continued evaluation of the complete fusion process. One example of case study is the map exploration by a blindfolded user with little experience: after fusion, 98% of the detected fingers were identified (name of finger and hand). For each finger it was possible to determine whether it touched the surface or not. 95% of the detections were identified as touches which means that most of the time the subject was using all of his fingers. Both hands were used almost equally. His left ring finger was the finger having the most contact with the map (19%), whereas it is not typically used for map exploration by an experienced visually impaired subject. The thumbs were least used with only 3.4% of touches. The fusion successfully removed false positives (mainly contacts of the palm in the lower part of the map). These results suggest that it is possible to analyze the output data after fusion to decipher users' exploration strategies.

Discussion + future work

We presented a novel approach for finger tracking during exploration of a tactile drawing. The prototype included a raised-line map on top of a multi-touch table and a Kinect camera observing hands and fingers. We implemented and compared two algorithms for finger tracking, one using a RGB image and one using a depth image. The depth image algorithm presented errors when fingers were closed. On the contrary, no specific preparation was necessary. The RGB image algorithm was very stable and compatible with different users' exploration strategies. It would be portable for cameras with higher resolution and thus higher coordinate precision. However, users needed to wear color markers which demanded additional preparation time (less than 5 min). Also, the markers on the fingers might hinder natural exploration movements. Hence, we recommend using very little markers (e.g. nail polish). Preliminary tests showed that it was possible to merge video and touch inputs. The fusion identified hand and finger positions for 98% of all detections with accuracy of 5.6 mm (0.28 mm for touch events) and a 10 Hz frequency. It also determined whether fingers were touching the surface or not. Adventitious touches from other body parts were removed quickly and easily.

We are currently working on an advanced prototype. Among other things, we want to investigate the combined usage of both cameras in order to improve the finger detection algorithm. We are also working on visualizing the fusion results. We suggest that drawing finger traces and matching them to the map content can be helpful for analyzing exploration strategies from both a spatial and temporal perspective. Figure 7 shows which map regions are explored the most often by the right index finger of a visually impaired user. In addition to this spatial analysis of the exploration, we also visualized finger traces over different periods of

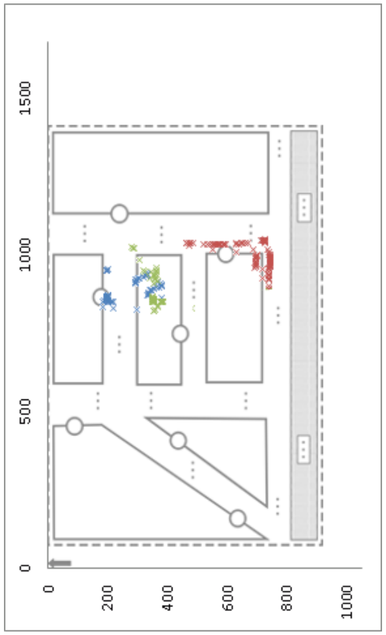

Figure 7: spatial and temporal visualization of movements made by the right index (see colored traces) during map exploration matched to the map content. Colors indicated the successive production of movements (1 red, 2 green, and 3 blue).

time, using different colors to specify their temporal order of appearance.

Thanks to this prototype, we will be able to decipher haptic behavior that lead to successful exploration of a tactile map. The first step will be the automatic classification of output data according to different haptic exploration strategies [see 12]. The next step will be a series of experiments with visually impaired users. We hypothesize that both the type of strategy and the interaction method used for map exploration have an effect on cognitive mapping.

To conclude, we have shown that it was possible to combine multi-touch and Kinect sensing to better capture the users' hand motions on a surface. We applied this system to a map exploration program for visually impaired users. Beyond the exploration of tactile maps, our combined system offers an interesting and novel apparatus for learning about how visually impaired users read a variety of pictures with their sense of touch. In addition to providing future guidelines for teaching efficient picture reading to visually impaired people and for designing interaction techniques, our system might also be used as a training device itself. It might assist visually impaired people in learning how to scan pictures successfully through providing online corrective feedback during the manual exploration (e.g., an auditory feedback could help users to modulate their finger movements to optimal trajectories, velocity and pressure parameters).

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