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EXPLORING MAPS WITH TOUCH: AN INCLUSIVE HAPTIC DEVICE

Katerine Romeo¹, Simon Gay¹, Marc-Aurèle Rivière¹, Edwige Pissaloux¹

¹LITIS, CNRS/FR 3638, University of Rouen-Normandy, France

Katerine.Romeo@univ-rouen.fr

Abstract

This paper presents a preliminary case study for the accessibility of maps for Visually Impaired People (VIP) using a novel haptic interface called F2T (Force Feedback Tablet). This device allows VIP to actively explore and feel graphical content and receive feedback on the explored image properties through a combination of dynamically generated force-feedback effects. Simplified room layouts were displayed to VIP, each including an entrance, an exit, and walls with a variety of angle shapes between them. The obtained results indicate that the F2T allows VIP to recognize different types of room layouts with good accuracy (with a mean absolute error of less than 10° when identifying angles between walls), and also shows the usefulness of the “guided” exploration mode to hasten the discovery of an unknown layout.

Introduction:

In our current digital society, graphical data is becoming increasingly ubiquitous. Most information sources have been digitized, and the advent of smartphones, social media platforms and wearable smart devices have powered an ever-growing exchange of video and image content over the web. Thus, culture and education are getting increasingly reliant on pictures, schematics, videos or maps, and accessing such information is difficult for Visually Impaired People (VIP). Traditional screen readers and braille devices are not adapted to tap into this flow of information, limiting VIP’s inclusion in society and lowering their quality of life.

For VIP, accessing maps and graphical content often requires specifically designed documents in relief, such as maps with magnets, thermoformed surfaces or 3D representations of objects. However, such representations are often expensive to print, represent a static set of elements with a fixed scale and level of details, and require well-thought simplifications to be intuitively understood.

During the last decades, many efforts have been made to develop interfaces allowing to dynamically display / convey graphical contents to VIP [1], [2], using various types of interfaces such as taxel matrices [3], electro-tactile surfaces [4] or plain vibrators [5]. However, despite their advantages in being able to display different types of contents and dynamic information, very few haptic devices are actively used by VIP [6]. One of the reasons for this lack of adoption is the difficulty to recognize and differentiate objects displayed through those devices. Indeed, most touch-feedback technologies either provide edge or texture-based perception, thus presenting an incomplete representation. This greatly limits their use for the comprehension of graphical information

The F2T (Force-Feedback Tablet) [7] was developed to provide a new way for VIP to explore and intuitively interpret graphical content such as maps and images. It allows VIP to explore and feel graphical content through an interactive interface that generates haptic effects based on the underlying content of the image. Those haptic effects encode specific spatial properties of the image (such as edges or textures) depending on where the user is directing the focus of its exploration.

This paper explores the usability of the F2T for assisting the discovery of 2D indoor plans. Indeed, previous research has shown that haptic displays can effectively support interpreting map-based

information [8], [9], but these haptic dynamic representation of maps are often difficult to interpret and memorize. To allow for an intuitive exploration, such devices should provide information to both localize and distinguish the various elements (i.e. objects or areas) of the image. Combining the various force-feedback effects of the F2T with the users' movements, should allow them to perceive both the edges of objects and to give an identity to those objects by linking them to different haptic "textures", thus helping VIP gain a more accurate mental images of the explored contents [10], [11].

The next section summarizes the main principles of the F2T and the following one presents preliminary results obtained using the F2T to explore simplified geographic maps.

F2T or an inclusive haptic device:

The F2T allows VIP to explore and feel maps (and other graphical contents) by moving a small mobile platform held by motorized axes over a virtual image (cf. Fig. 1). They guide the platform by pushing a joystick placed on it and receive dynamically generated haptic feedback based on the content of the currently explored region of the image (which is defined by where the platform is over the virtual image). The user can both freely explore the image or be guided through it by the device itself. It uses various force-feedback effects to provide information about relevant properties of the explored image, such as the nature of the currently explored section (e.g. corridor, room, wall, ...), the presence of a path or of points-of-interests (PoI), etc.

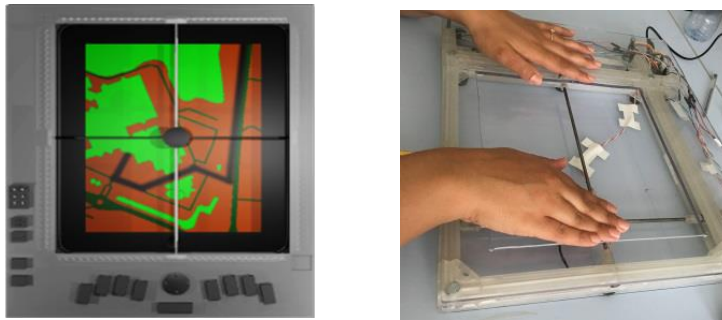


Fig. 1 Model of the F2T (left) and its current prototype (right): a flat thumbstick (center of the tablet) acquires user's intended movements; the actuated support moves the thumbstick to generate a large variety of haptic effects from images displayed on a screen to which the F2T is attached.

The F2T's control system allows a wide range of interactive haptic effects to represent the content of an image. Those effects vary by the amount of "control" exerted over the movement of the mobile support by the device itself.

On one end of the continuum, *passive effects* will slightly alter the final movement of the support, compared to the user's intended movement. Those effects usually apply a speed or direction correction to the intended movement. For example, a specific room could be distinguished from the neighboring area by having a high "friction" coefficient, requiring more efforts to cross (by moving the joystick through it). This resistance can be constant on the whole room, or could increase in a stepwise manner, to indicate stairs. Similarly, walls could be indicated by a "vertical step" that needs to be overcome by pushing the joystick with a certain threshold of force to be able to "move over" the wall, akin to climbing a cliff-face. Finally, those effects can be combined to create more complex ones, such as "canyons" that aim to keep the support within a specific "rivulet" by dragging it back towards its center when the user tries to move away from it, akin to trying to escape gravity well. This effect can be used to encode preferred paths, from which you can divert but to which you will always be brought back, unless you find another of those paths to "fall" into.

On the other extreme of this continuum, you have active effects, which are different types of guidance modes, where the device guides the user along a predefined path. Depending on the type of guidance, the user is either fully locked onto that path, or can slightly deviate from it, but cannot escape from it or stop its progress, akin to swimming laterally into rapids.

The following experiments explore how to combine those effects in order to convey cartographic data into haptic stimulations, allowing VIP to efficiently explore and mentally represent the spatial organization of simple indoor plans.

Test protocols and results:

Previous preliminary evaluations showed that the F2T can be used to convey basic geometric shapes and movements [11]. To further extend those results to more complex shapes and tasks, we designed two simple experiments: identifying the angle between two walls and recognizing the layout of a room (composed of several walls with different types of angles between them). Twelve blindfolded sighted participants were enrolled for both studies, with 9 participants between the ages of 20 and 30, and 3 between 30 and 50 years old.

Angle perception:

To verify that the F2T allows blindfolded participants to perceive and identify various angles, we prepared six different haptic images representing acute, right and obtuse angles (c.f. Fig. 2). The angles were presented in a randomized order, and no other information on the types of angles to expect was given to the participants. Each haptic image covered the exploitable surface of the F2T (20 x 20 cm). The green areas represent virtual walls and cannot be crossed.

For each trial, the participant could freely explore the image and was given the guideline of following the edges of the virtual wall to identify the angle between the two walls as fast as possible and give its approximate value orally. Participants could express angles greater than 180° by giving the complementary angle if they felt more fluent with salient angles. The exploration time needed to give an answer was also recorded.



Fig. 2 Angles of 45°-90°-135° (top row) and 315°-270°-225° (bottom row) presented in a random order during the test.

Fig. 3 shows the average exploration times (in seconds) and the Mean Absolute Error (MAE, in degrees) when identifying the angle for each angle value. The average exploration time was 58.5 seconds with a standard deviation of 12.8 seconds. The exploration times were longer for the angles greater than 180°. Such results are probably due to larger surface (black) which had to be explored, and the increased facility of “loosing” the edge when sliding against it. Indeed, it was observed that the user’s finger moving too fast could lose the edge of angles greater than 180°, making participants loose time during their exploration.

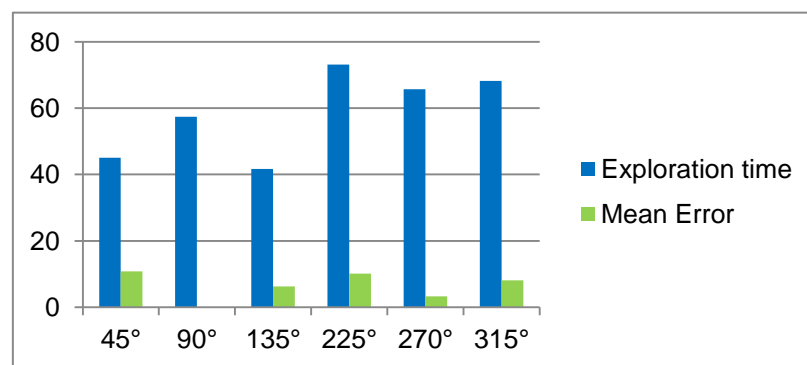


Fig. 3 Average Exploration Times (in seconds) and Mean Absolute Error (in degrees) for the six angles

The highest MAE (of 9.5°) was observed for 45° and 315° angles, while the MAE is around 8.2° for 135° and 225° angles. Right angles (90° and 270°) were the most easily recognized ones, with a MAE of 0° and 3.33° respectively.

Layout perception:

The following experiment consisted of haptic images combining several walls (impossible to cross) at different angles, into four basic room layouts (c.f. fig 4), each with an entrance and an exit, indicated by a specific passive friction effect. Each layout was presented with the entrance facing the user, at the bottom of the layout, to give the participant the feeling of entering the room.

The same 12 participants were asked to explore and memorize each layout and then draw it, including the position of the exit door. Participants were divided in two groups: half of the participants explored the layout freely until they felt comfortable enough to draw it, while the other half was first guided around the virtual room through a path showing the exit door, before being allowed to freely explore the room until they felt confident in drawing its shape. Each of the 4 virtual rooms was presented in ascending order of topological complexity. They were told that those 4 rooms were part of an apartment, each room connected to the next by its exit.

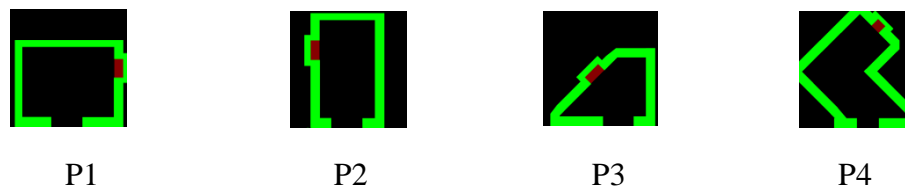


Fig. 4 Each of the 4 virtual rooms, in order of complexity.

Fig. 5 shows two sets of the collected drawings for each of the 4 layouts. Each participant was able to easily find the location of the exit door and to correctly reproduce the layout. The 2 rooms with diagonal walls (P3 and P4) were generally more confusing, with some participants pointing out the difficulty to remember the position and angles of all walls.

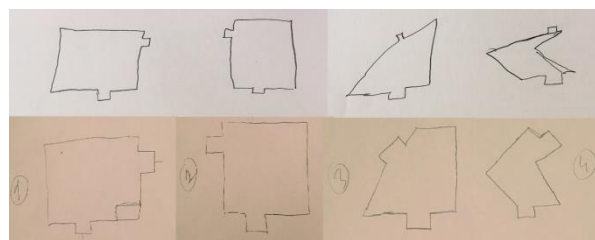


Fig. 5 Two sets (upper and lower lines) of drawings of the 4 virtual rooms.

The average exploration times are shown in Fig. 6. The free exploration time in the non-guided condition were longer ($\mu = 95.4s$) than in the guided one ($\mu = 53s$). This means that the guided exploration allows users to understand (and mentally represent) the structure of the layout while they are guided, thus reducing the time they need to freely explore it before being comfortable drawing it.

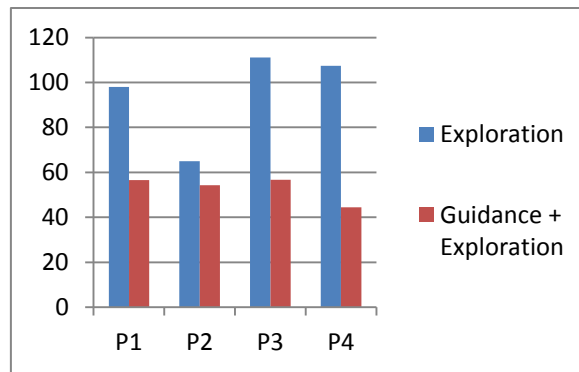


Fig. 6 Average exploration time of the rooms.

Interestingly, the last 2 layouts generally required longer explorations times in the non-guided condition (due to the non-straight walls and angles), but this difference wasn't observed in the guided condition. The greater difficulty in mentally representing the last 2 layouts could be partially explained by the thumbstick producing non-smooth and sometimes slightly curved diagonal movements due to the current prototype's imperfections.

Similarly, participants took more time exploring the first room due to the novelty of the task, but only in the non-guided condition. The participants found that the guidance was very useful to better and faster apprehend the explored layout and confirmed that a free exploration phase was required afterwards to consolidate their understanding of the room's layout. Some participants also reported that the used guiding speed was sometimes too high;

These preliminary results show the F2T's potential to allow the comprehension of haptic images of spatial data such as maps. And despite a lack of quantitative results to validate its usefulness, participants highlighted the usefulness of the guided exploration to rapidly give them an overview of the whole layout, allowing them to explore it more efficiently after.

Mental Representation of the whole apartment:

The final task the participants were given was to draw the whole apartment by linking the four interconnected rooms they previously explored. This task required them to mentally rotate some of the rooms in order to connect the exit of a room with the entrance of the next in a coherent manner. Fig. 7 presents the expected result and two examples of the collected drawings for this task, which was correctly accomplished by all the participants.

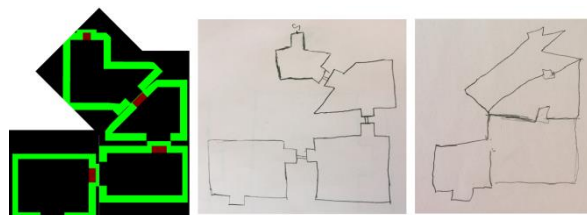


Fig. 7 Four interconnecting virtual rooms and two examples of drawings of the mental representation of the connecting rooms.

Conclusions:

This communication introduces a potential use case for the Force-Feedback Tablet, a novel haptic interface allowing VIP to intuitively explore and interpret images such as cartographic data through a combination of haptic effects. Simple experiments were designed to evaluate the spatial cognition of blindfolded participants (such as the mental rotation of layouts) using the device to explore cartographic data. The results obtained are encouraging but will need to be confirmed with more robust protocols to more reliably test specific hypothesis on the relative importance of specific haptic effects for representing relevant elements of cartographic data (such as points of interests,

elevators...). The possibility of adding localized audio cues to identify “noisy” elements of the map (such as fountains, coffee shops...) is also being studied.

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