Towards Haptic Surface Devices with Force Feedback for Visually Impaired People

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Abstract. This paper presents a new haptic surface tablet that can provide force feedback to the user. Force feedback means that the device can react to the user's movements and apply a force against or in-line with these movements, according to the tactile properties of a displayed image. The device consists of a frame attached to a tactile tablet that generates a force feedback to user's finger when exploring the surface, providing haptic informations about the displayed image. The experimental results suggest the relevance of this tablet as an assistive device for visually impaired people in perceiving and understanding the content of a displayed image. Several potential applications are briefly presented.
Keywords: haptic accessibility to 2D images, assistive device for visually impaired, force feedback, Haptic surface

1 Introduction

Visually Impaired People's (VIP) access to 2D information is still an open question with no fully relevant technology proposed yet. Existing commercially available devices and academia prototypes have several drawbacks which prevent VIP from using them on a daily basis. Indeed, these devices are usually dedicated displaying only one type of data: texture or shape or Braille coded text. For some of these devices, VIP have serious difficulties recognizing simple forms because they cannot feel the edges and their exploration is not assisted [1]. Therefore, a device of new type should be designed and prototyped. This paper proposes such a solution: a Force Feedback Tablet (named F2T), which allows users to feel the edges and textures of 2D objects, and assists the image exploration.

The paper is organized as follows: Section 2 gives a review of existing technologies for haptic devices; Section 3 adresses the concept of the F2T, its working principles and its functionalities, Section 4 explains the F2T simulator's usage and on-going applications. Section 5 encompasses some conclusive remarks and future developments of the F2T project.

2 Status of haptic devices

This section reviews existing devices that can display and convey 2D images on a surface (such as a screen) through tactile stimultion. We classified haptic technologies for touch stimulation devices into three groups, based on the method used to convey tactile *stimuli*: haptic tablets that physically modify their surfaces, haptic tablets whose screen stimulates the user's skin, and wearable devices that apply haptic stimuli directly on the skin of the user (e.g. haptic glove and stylus-like devices).

2.1 Haptic modifiable surfaces

These devices produce a tactile image using a matrix of movable pins called *taxels* (tactile elements). By moving taxels up and down, it is possible to display the edges and relief of an object. A large variety of actuators are used in academic and commercial devices: piezzoelectric benders (*Hyperbraille* [2]), solenoids (flat solenoids in the *BlindPad* [3] and bi-stable solenoids in *Graphical Interface* [4]), electric motors (*InFORM* [5]), and shape memory alloys (SMA) (*TactiPAD* [6]). The advantages of these devices is that they can produce images similar to bas-relief that can be explored with all fingers. However, the size and number of actuators reduces the resolution of displayed images, and makes those devices heavy and expensive.

To reduce these problems, Orbit Research developed the *Graphiti* tablet [7], that uses only one motor per line and per column of pins. However, images cannot be refreshed instantly because all the pins cannot be moved simultaneously. Inventivio GmbH proposes the *Tactonom* [8], that generates images with little steel balls, through a process similar to printing. Although this principle allows high resolution images (the Tactonom device generates images of 10,500 taxels), the image update takes several seconds. A version of the *BlindPad* [9] uses a matrix of cells made of shape memory alloys and an air pump. Electrodes can heat up SMA cells to make them ductile, while the pump blows in or out to push or retract the cells. The refreshment rate is however limited by the heating and dissipation time.

Although these principles reduce the number of actuators, they increase the image update delay. The *Virtual Tactile Display* [10] uses a taxel surface based on the *OPTACON* [11], that the user moves over a large surface, reducing the number of actuators. This principle makes it possible to reduce the number of actuator and to provide real-time image refreshment, but makes it impossible to freely explore the surface with multiple fingers.

Although taxel surfaces allow for easy exploration, they suffer from serious disadvantages: they have a poor resolution, are heavy and expensive. Several solutions allow to reduce these problems, but at the cost of the image refreshment rate or the possibility of free exploration. Moreover, those solutions do not allow the transmission of essential surface properties of the image, such as textures.

2.2 Stimulation screen devices

These devices stimulate the user's skin by modifying the screen properties. Unlike taxel tablets, this technology makes it possible to reproduce textures with high resolutions. Another advantage is that the haptic surface can be transparent and placed over a screen, to improve interaction with sighted people. The most common solution is to make the surface vibrate using piezoelectric vibrators. The *StimTAC* [12] tablet uses vibrations (stationary waves) to generate an air cushion between the user's finger and the screen surface, modifying the friction at the contact point. *Hap2U*'s tablet [13] uses several patterns of vibrations to stimulate user's skin receptors and simulate different kinds of textures. The *TeslaTouch* tablet [14] modifies friction through electro-vibrations: by applying high tension between the finger and a conductive layer under an insulated screen, the device generates an attractive electric force that increases friction between the surface and finger.

Haptic stimulation tablets are lighter and less expensive than taxel tablets. As they can be used with a screen, they enable new applications for sighted people, and facilitate the development of viable products for the general public. However, they are limited to a single-touch usage and they do not allow to sense object edges, making it difficult for VIP to identify shapes.

2.3 Wearable devices

These wearable devices reproduce tactile stimuli directly on the skin of the user, through vibrations and/or taxels, while exploring a surface such as a standard tactile tablet. As stimuli are delivered at specific locations of the skin instead of the whole surface, these stimuli can be generated with only a limited number of actuators and with less energy. Moreover, as stimuli can be provided whether the user is touching a surface or not, more general applications, such as environment exploration, can be considered. The *TactiNET* [15] uses a piezoelectric transducer on each finger to simulate textures, and the *Soft-Actuator-Based Wearable Tactile Display* [16] uses a matrix of dielectric actuators worn under the fingertips, working like a tiny taxel surface that the user can use to explore a large surface. A stylus can be easier to use than gloves, but it is limited to single-touch applications. The *TactiPen* [17] uses a Braille cell which allows to read texts. The *Ubi-pen* [18] provides both edges stimuli, through a matrix of taxels, and textures thanks to a vibration motor. The tip of the *Reflective Haptics Touch Pen* [19] consists of a metal ball, that can be slowed down by a magnetic field, simulating friction changes.

Several devices stimulate mechanoreceptors through stretching skin: Gleeson, William and Provancher [20] propose a device where a *tactor* can stretch fingertip skin. Guinan *et al.* [21] integrated this device in thumbsticks of a joypad. The *STReSS* device [22] uses a little matrix of 64 piezoelectric actuators that laterally stretch finger skin when the user laterally explores the surface.

Wearable devices solve several problems met in haptic surfaces: the number of actuators is very limited, and they can be used with regular tactile tablets. However, these devices have to be worn during the whole utilization time, which can make them uncomfortable after long periods, or require to carry and manipulate a stylus in addition to the tactile tablet.

The above short review shows that there is no touch stimulating device that could display both edges and textures of a tactile image, while being light, inexpensive and easy to use. Indeed, these requests seem mutually exclusive when considering the physical phenomena involved in haptic stimulation technologies. Moreover, none of these devices guides the exploration of the displayed information. The F2T offers a new alternative to overcome the limits of the aforementioned categories of systems.

3 Principle of the F2T system

The F2T's aim is to allow VIP to perceive edges and textures without using taxels. A force feedback is used to simulate the edges of a virtual object and guide the finger when following them. Several force feedback 3D pointing devices are available on the market, such as 3D mice (e.g. *Novint Falcon*) and stylus (e.g. *3D System Touch*), but their force feedback systems are based on complex mechanisms, such as robotic arms, which make them expensive and hardly portable. To overcome these disadvantages, we propose a 2D force feedback system based on a very simple actuator system. F2T is based on a mobile support integrating a flat thumbstick on the top. This support is constrained and moved by two actuated orthogonal axis X and Y (Figure 1). The support position is servo-controlled by the thumbstick to follow the user's finger. Several offsets can be added to this servoing control, according to the support position over the displayed tactile image, to simulate edges and textures through force feedback: a force effect simulating objects' height variations and edges, a fluid friction force and a solid friction force simulating textures of the current object point. The resulting movement $\overrightarrow{V}$ of the mobile support is given by (1):

$$\overrightarrow{V} \;=\; (\;\overrightarrow{V_1}\;-\;\delta . F_{s(x,y)} . \frac{\overrightarrow{V_1}}{|\overrightarrow{V_1}|}\;)\;.\;f_{s(x,y)}\quad;\quad f_{s(x,y)} = \begin{cases} 1 \text{ if } |\overrightarrow{V_1}| \geq F_{s(x,y)} \\ 0 \text{ else} \end{cases} \qquad (1)$$
$$\overrightarrow{V_1} \;=\; \alpha . \overrightarrow{J} \;-\; \beta . \overrightarrow{G_{(x,y)}} \;-\; \gamma . F_{f(x,y)} . \overrightarrow{J}$$

$\overrightarrow{J}$ is the thumbstick input vector, $\overrightarrow{V}$ is the speed vector of the mobile support, $\overrightarrow{G_{(x,y)}}$ is the surface gradient (slant) at current position (x,y), and $F_{f(x,y)}$ is the fluid friction at (x,y). f_s and $F_{s(x,y)}$ characterize the solid friction. α, β, γ and δ are coefficients linked to the materials and actuators used for the F2T. α is the servoing coefficient, β, γ and δ weight the different forces applied to the mobile support. Therefore, it is possible to simulate both the edges and textures of objects.

An interesting aspect of this force feedback system is that it can also guide the user's finger, which opens new possibilities for VIP assistance, (cf. section 4). The guiding possibilities can be enabled by moving the mobile support without considering the thumbstick values. It is then possible to move the support according to a predefined trajectory (e.g. to draw a figure or a path on a map, or to move toward the location where a relevant information is displayed).

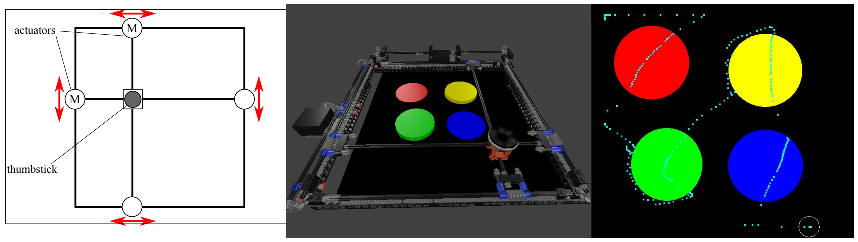

Fig. 1. Left: principle of the F2T. A mobile support, with a thumbstick on its top, is servo-controlled to follow the thumbstick movements. Offsets can be applied to this position control, generating a force feedback. Middle: simulated F2T based on the *Blender Game Engine*. The thumbstick is represented on the orange support. Right: RGB image describing the tactile properties of the surface: red channel indicates fluid friction, green channel indicates elevation and blue channel indicates solid friction. While exploring the surface, we experience fluid friction when moving on red and yellow discs (the mobile support is slowed down), edges of green and yellow circles, allowing to follow them by gently pressing the thumbstick, and solid friction on the blue disc (the support remains stuck if we do not press the thumbstick hard enough).

4 Exploring 2D surface with the F2T

A simulator of the F2T (Figure 1) was developed using the Blender Game Engine[1]; its control system was developed in Java. The user can interact with the tablet using the thumbstick of a standard USB gamepad. The tactile properties of the picture are defined using the following RGB color code: the red channel indicates fluid friction, green indicates height and blue indicates solid friction. A cyan dot is marked every 100ms to record the previous positions of the support and observe speed variations. Figure 1 (right picture) gives an example of tactile surface with a surface with high fluid friction (red disc), an elevated smooth surface (green disc), an elevated surface with high fluid friction (yellow disc) and a surface with high solid friction (blue disc). We then move on the surface while observing the reactions of the simulated tablet (Figure 1 left). When we move on the red circle, the support is significantly slowed down, simulating a fluid friction. When we move on the green (elevated) area, and gently pressing the thumbstick, the support resists to the movement and *slides* along the circle edge. We need to press the thumbstick harder to make the support move on top of the green area. When the support leaves the green area, we observe a short jump: indeed, the surface gradient is negative, therefore the support moves in the same direction as the thumbstick, simulating the *descent* of the support. We observe similar reactions when moving on top of the yellow area, because it is both an elevated and rough surface. The blue surface simulates solid friction when the support moves over it. While we gently press the thumbstick, the support cannot move. When we press the thumbstick hard enough to overcome the friction, the support moves, but with a constant resistance.

[1] https://docs.blender.org/manual/en/dev/game_engine/index.html

Several applications of the F2T have already been investigated using this simulated tablet. The following applications demonstrate the possibilities of the F2T (texture, relief and edge display and guiding possibilities):

Access to art works. The proposed approach [1] allows to discover the content of a painting by providing a tactile representation of the main objects in the scene. The assisted exploration of objects' edges allows faster understanding of the scene, as it is possible to guide VIP while describing the story of a painting/picture through audio feedback. Indeed, F2T assists with the spatialization of all the elements, and helps the user draw complex shapes to better imagine them.

Reading assistance. For this application, each line of *text* is represented as a trench that guides the finger, and makes it possible to follow lines and to count them. By adding Braille cells or text-to-speech capabilities, the F2T would allow to access text in a spatial way rather than in a sequential way. It is possible to make automatic carriage return and to follow links (such as figure reference or footnote) using the guidance mode. Figure 2 shows an example of tactile image that we tested with the simulated tablet. We observed that while we gently press the thumbstick, the mobile support is maintained in the trench and slides along the line. We need to press the thumbstick strongly to move out of the trench. The support then reacts as it jumps from one trench to another. These jumps can be used to count lines and localize specific information in the text.

Journey preparation assistance. In the example given in Figure 3, buildings are represented as high surfaces, roads as smooth surfaces, and accessible areas as rough surfaces. The path of a journey is represented as a trench, that guides the user through the main path. However, it is still possible, by pressing the thumbstick harder, to move out of the trench and explore surrounding areas. In this map example, we followed the main path, then explored surrounding areas by following a secondary path (smooth surface) before returning to the main path until reaching the destination. The guidance possibilities allows to show

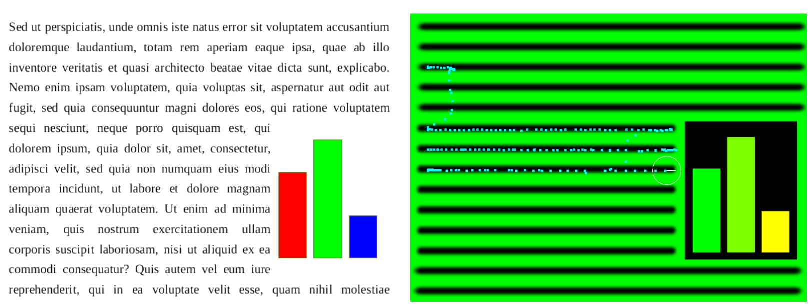

Fig. 2. Reading application. Each line is represented as a trench (dark lines) that guides the finger. Text can be read with a braille cell on the side of the tablet or with a text-to-speech system. These trenches allow to count lines and spatialize information. The guidance possibilities allow to guide the user for an automatic carriage return, to move from a reference link to a specific information (e.g. reference, figure or footnote).

Fig. 3. Left : map from OpenStreetMap. Right: simplified map. The path is a trench (black) that guides user. Building are elevated places, surrounding areas are rough surfaces and other paths are smooth surfaces. The user's finger is guided by the main path. It is however possible to explore surrounding areas too. The guidance possibilities allow to show the main path in order to help user spatialize it, before letting the user freely explore the area.

the path and locate nearby important places, enabling the user to spatialize important places before freely exploring the environment.

5 Conclusion and future work

We proposed a haptic surface that partially corrects the disadvantages of current haptic devices, as mentionned in section 2. Indeed, the F2T system allows to represent both edges and textures of objects, with a high resolution and no latency, while being light, inexpensive, and easily scalable. Moreover, it brings a new feature: guiding the user's finger, allowing the device to further interact with him, and to help him to spatialize information. We hope that this system will enable new assistive uses for VIP, and help better understand how we construct our spatial perception from touch, thanks to the human-machine interaction possibilities it provides. In our future endeavors, we plan to test the F2T with VIP and develop an improved version of the device, like a multi-touch system (using multiple thumbsticks), a better texture feedback using a piezoelectric vibrator on the thumbstick, and an actuated support to move the thumbstick up and down to improve the experience of relief.

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