Ubi-Pen: Development of a Compact Tactile Display Module and Its Application to a Haptic Stylus

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Abstract

The objective of this research is to propose and design a compact tactile display module and verify its performance in a pen-like haptic interface. A small, safe, silent and light tactile display module with a low power dissipation has been built. Based on this module, we present the Ubi-Pen, a system providing texture and vibration stimuli. Preliminary evaluations indicate it can satisfactorily represent tactile patterns. We also investigate the optimal frequencies at which to present stimuli, and evaluate its capacity to support GUI operations by producing a simple click-like feedback when buttons are pressed.

1. Introduction

As demand for more realistic communication methods with computers increases, haptics has emerged as a promising element in the field of computer interfaces. Particularly for tasks like real manipulation and exploration, the demand for interaction enhanced by haptic information is on the rise. Indeed, it seems likely that haptic interfaces will become more and more essential as computer interfaces evolve and one day become as commonplace as today's visual and audio interfaces [3].

Researchers have proposed a diverse range of haptic interfaces. Force feedback devices, which have attracted the most attention with their capacity to physically push/pull a user's body, have been applied to game interfaces, medical simulators, training simulators, and interactive design software, among other domains. However, compared to force feedback interfaces, tactile displays have not been deeply studied. This is at least partly due to the fact that the miniaturization necessary to construct such systems requires more advanced electronic and mechanical components. However, it is clear that haptic applications for mobile devices such as PDAs, mobile computers and mobile phones will have to rely on tactile devices. Such a handheld haptic system will only be achieved through the development of a fast, strong, small, silent, safe tactile display module, with a low heat dissipation and power consumption.

A number of researchers have proposed tactile display systems. In order to provide tactile sensation to the skin, work has looked at mechanical, electrical and thermal stimulation. Most mechanical methods involve an array of pins driven by a linear actuation mechanism such as a solenoid, piezoelectric actuator, or pneumatic actuator. An example is the "Texture Explorer", developed by Ikei [4]. This 2×5 flat pin array is composed of piezoelectric actuators and operates at a fixed frequency (~250Hz) with maximum amplitude of 22μm. Summers *et al.* [5] developed a broadband tactile array using piezoelectric bimorphs, and reported empirical results for stimulation frequencies of 40Hz and 320Hz, with the maximum displacement of 50μm. Since the tactile displays mentioned above may not result in sufficiently deep skin indentation, Kyung *et al.* [6] developed a 5x6 pin-array tactile display which has a small size, long travel and high bandwidth. However, this system requires a high input voltage and a high power controller. As an alternative to providing normal indentation, Hayward and Cruz-Hernandez [7] focused on the tactile sensation of lateral skin stretch and designed a tactile display device which operates by displaying distributed lateral skin stretch at frequencies of up to several kilohertz. Recently, they and their colleagues applied their concept to mobile interaction scenarios by developing a compact system, and then considering and evaluating specific focused use-cases [2]. However, it is arguable that the device remains too large (and high voltage) to be realistically integrated into a mobile device. Furthermore, despite work investigating user performance on cues delivered by lateral skin stretch, it remains unclear whether this method is capable of displaying the full range of stimuli achievable by presenting an array of normal forces.

Konyo *et al*. [8] used an electro-active polymer as an actuator for mechanical stimulation. He proposed a tactile device to express the fine texture of a cloth

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surface using vibration rates of up to 100 Hz. However, the stiffness of the soft polymer gel was insufficient to achieve the desired results. Some research deals with electrical tactile display devices. Poletto and Doren developed a high voltage electro-cutaneous stimulator with small electrodes [9]. Kajimoto *et al*. [10] developed a nerve axon model based on the properties of human skin and proposed an electro-cutaneous display using anodic and cathodic current stimulation. Unfortunately, these tactile display devices sometimes involve user discomfort and even pain.

In the paper, we propose a compact tactile display module which can be embedded into small devices and a pen-type haptic interface providing vibration and distributed pressure. In section 2, the design parameters and structure of the proposed tactile display module are described in detail. In section 3, the implementation of a pen-like haptic interface including the tactile display module and vibrating motor is presented. In section 4, we evaluate performance of this system, which we term the ‘Ubi-Pen’. Finally, in section 5, we discuss applications of the proposed system.

2. Compact Tactile Display Module

2.1 Design of a Tactile Display Module

In order to make a tactile display module, actuator selection is the first and dominant step. The actuator should be small, light, safe, silent, fast, powerful, consume modest amounts of power and emit little heat. This is a challenging list. Recently a very small ultrasonic linear motor ‘TULA35’ has been developed by Piezoelectric Technology Co.[1].

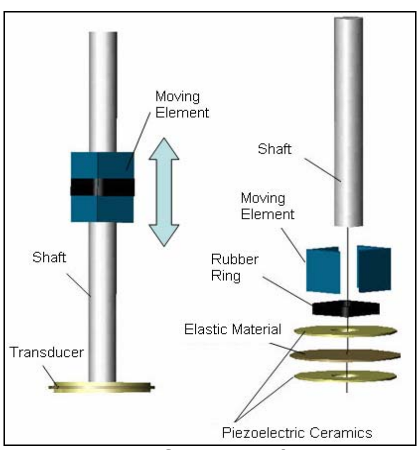

Figure1. Basic Structure of the Actuator

The basic structure of the actuator is shown in Figure 1 and driving principle is described in Figure 2. The actuator is composed of a transducer, shaft and a moving element. The transducer is composed of two piezoelectric ceramic disks and elastic material membranes. The convex motion of the membranes causes lift in the shaft of the motor. The fast restoring concave motion overcomes the static frictional force between the moving element and the shaft and makes the moving element maintain its position (Figure 2). Rapid vibration of the membrane at a frequency of 45 kHz causes rapid movement of the moving element. The diameter of the transducer is 4mm and its thickness is 0.5mm. The diameter of the shaft is 1mm and the standard length is 15mm. The thrusting force of the actuator is greater than 0.2N and the maximum speed of the moving element is higher than 20mm/sec.

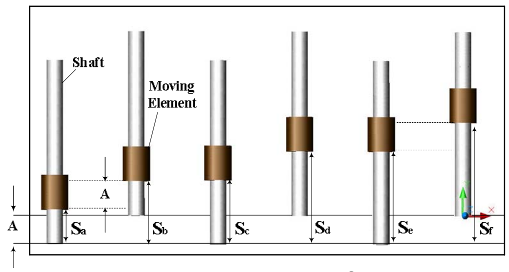

Figure2. Basic Driving Principle of an Actuator[1]

In order to minimize the size of the tactile display module, the actuators can be arranged as shown in Figure 3. Essentially, this figure shows an example of the arrangement of two variations on the actuators - each with different shaft lengths. This design minimizes the gap between actuators. Another feature is that the moving elements are in fact fixed together, causing the shaft to move when the actuators are turned on. This minimizes the size of the contact point with a user’s skin (to the 1mm diameter of the shaft), while maintaining the mechanical simplicity of the system.

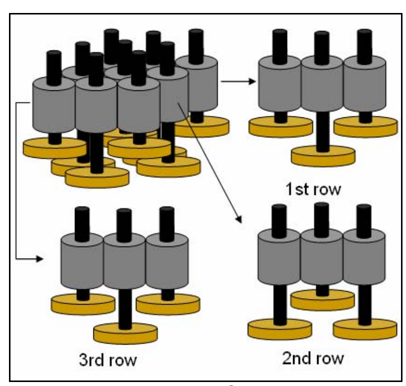

Figure3. Design Drawing of a Tactile Display Module

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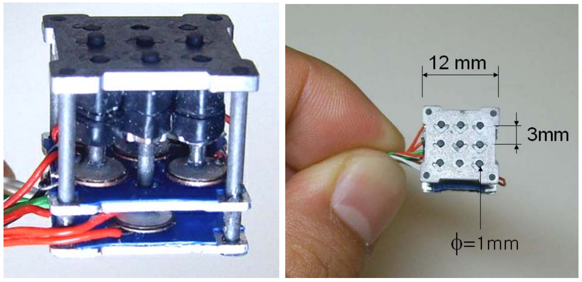

Figure 4. The Implemented Tactile Display Module

2.2 Implementation

From the design specification described in section 2.1, the prototype of the tactile display module has been implemented as shown in Figure 4. In order to embed the module in a pen, we constructed only a 3x3 pin array. However, it should be noted that the basic design concept is fully extensible; additional columns and rows can be added without electrical interference or changes in pin density. The shaft itself plays the role of tactor and has a travel of 1mm. Each actuator is controlled by a AD 5802 (Dual Piezo-electric PWM actuator controller, ADI). In future versions, it should be easy to minimize the size of controller as its maximum power consumption is only 400mW. The input voltage of controller is 12V. Since the actuators operate in the ultrasonic range, they produce little audible noise. The average thrusting force of each actuator exceeds 0.2N, sufficient to deform the skin with an indentation of 1 mm[12]. The total size of the module is 12x12x12 mm and its weight is 2.5grams. The bandwidth of the tactile display is approximately 20Hz when used with a maximum normal displacement of 1mm.

3. Implementation of Pen-like Tactile Display

The pen is a familiar device and interface. Since they are small, portable and easy to handle, styluses have become common tools for interacting with mobile communication devices. In the area of haptics, Lee *et al*. [11] suggested a haptic pen which could provide a sense of contact based around a touch sensor and a solenoid. It could generate a feeling corresponding to clicking a button. In order to support richer stylus based tactile cues, we embedded our tactile display module into a pen-like prototype. In addition, we installed a pancake-type vibrating motor in the tip of the pen to provide a sense of contact (See Figure 5). The housing of the pen was manufactured by rapid prototyping, and it has a length of 12cm and a weight of 15 grams. Currently, its controller is not embedded. We named this device the Ubi-Pen and intend it for use as an interface to VR, for the blind, to represent textures, and as a symbolic secure communication device. We also suggest it could be used generally as the stylus of a mobile communication device. Figure 6 shows a scene that a user is testing the Ubi-Pen on the mobile tablet PC.

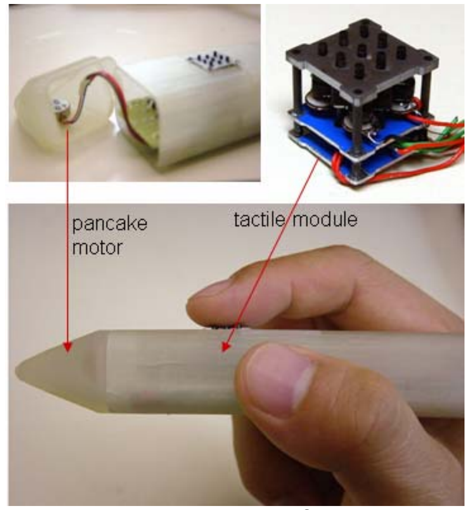

Figure 5. The Prototype of the Ubi-Pen

4. Evaluation of Performance

4.1 Braille Display of the Tactile Display Module

A common method to evaluate the performance of tactile displays is to test user's performance at recognizing specific patterns [4][6]. We use Braille as a stimulus set to conduct such a test. Specifically, we conducted a study involving the presentation of the Braille numbers 0~9 on the Ubi-Pen.


Figure 6. The Use of the Ubi-Pen

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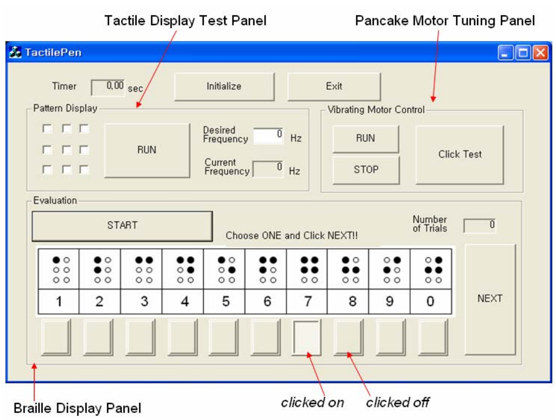

Figure 7. A Console for the Braille Display Experiment

Figure 7 shows the experimental console displayed on a tablet mobile PC. All studies were conducted on this platform. Subjects were required to hold the pen such that the tip of their index finger rested over the pin-array part of tactile display module. Prior to each of the studies, this posture was tuned and checked by activating each pin in turn and ensuring this could be felt by the subject. Subjects were also able to adjust the length of the vibration delivered by the pancake motor such that it fell in a comfortable and easily detectable range.

After this setup stage, we conducted a study on recognition rate of the 10 numeric digits in the Braille character set. As these can be displayed on only four pins, we mapped them to the corner pins on our tactile display module. We chose to do this as our user-base was composed of sighted Braille novices. We used three different stimulation frequencies: 0, 2 and 5Hz. Pins movement was synchronized. We presented 60 trials in total, each number at each frequency, twice. All presentations were in a random order, and subjects were not advised about the correctness of their responses. 10 subjects participated in the experiment. The Braille stimuli were generated continuously and changed as soon as the subject respond using the GUI. There were 2 minutes breaks after every 20 trials.

Table 1 shows the experimental results. Although all subjects were novice in using the tactile display, the average percentage of correct answers exceeded 80 percent.

	Average	Standard Dev.
Percentage of Correct Answer of All Subjects	80.83	11.23
Duration of Each Trial of All Subjects	5.24 s	1.94 s

Table1. Experimental Results

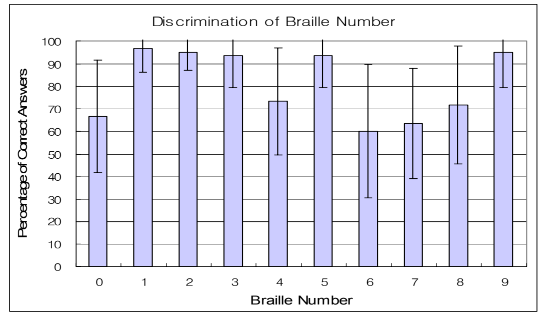

Figure 8. Discrimination of Braille Numbers

Figure 8 shows the percentage of correct answers by number presented; we can see considerable variation in these figures, and it is currently unclear as to its source. However, we conclude that the tactile display module shows satisfactory performance in a simple pattern recognition task.

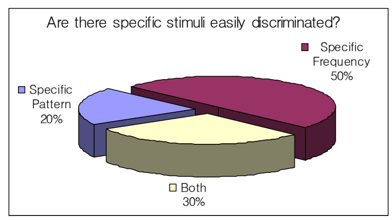

Figure9. Percentage of Choices

Previous work shows humans are more sensitive at a frequency band of 1~3Hz in tactile pattern discrimination that they are at surrounding frequencies. This is due to the structure of our neural mechanism for sensing tactile pattern. One part is easily activated by this frequency band [6]. Therefore, we hypothesized that stimuli delivered in that frequency range would outperform those outside it. This was brought out by asking subjects about their impressions of the cues, as shown in Figure 9. 8 of the 10 subjects suggested that some frequencies were easier to detect than others.

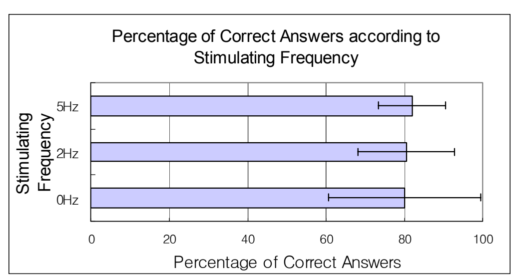

Figure 10. Percentage of Correct Answers according to Frequencies

However, as shown in Figure 10, there is no difference among the percentage of correct answers according to frequencies. Investigating in more detail,

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we turned to task completion time. As shown in Figure 11, the average duration of a trial is decreased at the 2 Hz frequency. Although, inconclusive, we suggest this indicates that subjects found the sensations delivered at this frequency to be easier to detect. In this section, the performance of the tactile display module has been verified. In addition, an appropriate stimulating frequency has been investigated.

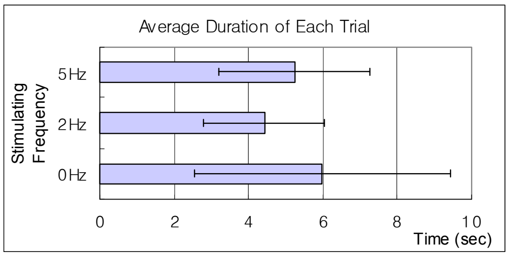

Figure 11. Average Duration of a Trial according to Frequencies

4.2 Effectiveness of Clicking Sense Feedback

Ubi-pen also possesses the ability to produce a click-like sensation, as described in section 4.1. Here we test the effectiveness of this feature. We set the duration of this feedback to 50ms and presented subjects with a simple calculator interface, shown in Figure 12. They had to enter each of the 6 equations shown on the right of the screen. Each equation was randomly presented and haptic feedback was also randomly provided in half the trials. Subjects had to calculate every equation twice until they obtained the correct answer to each. This calculator displayed only the results of calculations, not the figures entered. In this study we measured task completion time

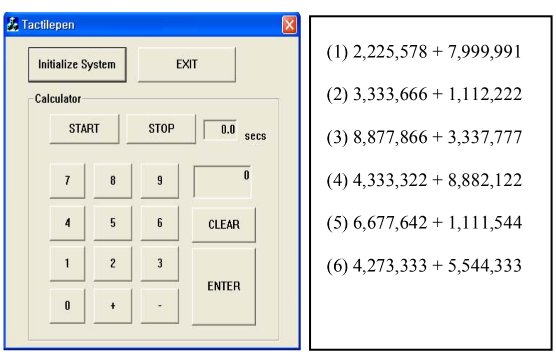

Figure 12. Calculator and Presented Equations

The experimental results in Figure 13 show that the clicking sense feedback of the Ubi-Pen decreased the length of time to enter the calculations. As shown in Figure 14, the major influence of the click sensation was to add self-confidence to users, and this contributed to the production of fewer errors and the reduced duration of the calculations. From this test, the effectiveness of the Ubi-Pen's click sensation has been verified.

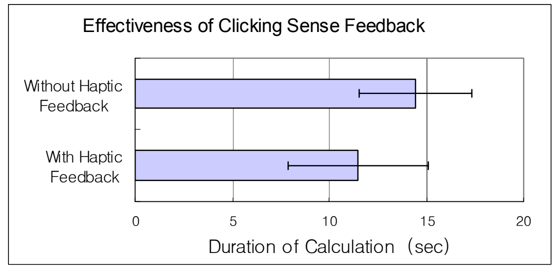

Figure 13. Effectiveness of Clicking Sense Feedback

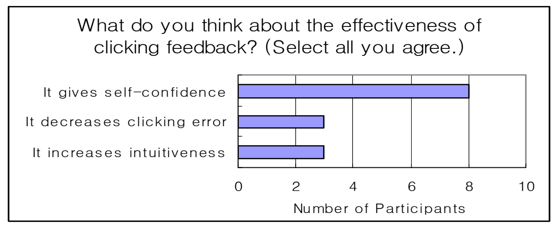

Figure 14. The Role of Clicking Sense Feedback

5. Application of the Ubi-Pen

As shown in Figure 15, the Ubi-pen mouse enables tactile pattern display. This program provides a symbolic pointer in the shape of a square, with a size of 15x15 pixels. A user can load any grayscale image. As shown in Figure 16, when the user touches an image on the touch screen with the Ubi-Pen, the area of the cursor is divided into 9(=3x3) sub-cells and the average gray value of each cell is calculated. Then, this averaged gray value is converted to the intensity of the stimuli displayed on each pin of the tactile display. Figure 16 shows the methodology of the pattern display.

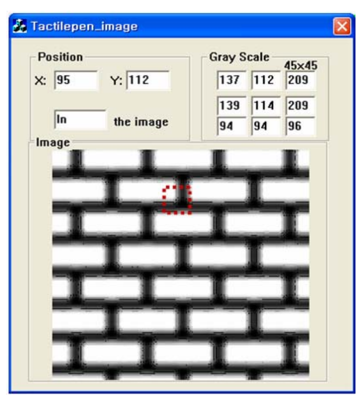

Figure 15. Texture Representation

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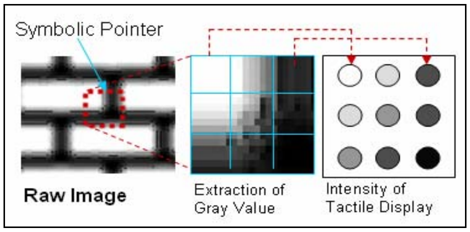

Figure 16. Methodology of Pattern Display

Since the tactile display module is small enough to be embedded into a force feedback device, the proposed module potentially realizes a force and tactile feedback device. Furthermore, the stylus interface of a pen-held haptic device (such as PHANToM^{TM})could be replaced by the pen-type interface we describe here. This may enrich information a user can feel in a virtual or tele-operated environment. In addition, the tactile display module might be installed in new mobile communication devices as well as PDAs and mobile computers.

6. Conclusion and Future Works

The objective of this research is to develop a compact tactile display module and verifying its performance in a pen-like form factor. As described in section 2, a small, safe, low power consuming, silent and light tactile display module has been built. Using the tactile display, we propose the Ubi-Pen which can provide texture and vibration stimuli. This system shows satisfactory preliminary performance in representing tactile patterns. Additionally, we take steps to determine an optimal stimulating frequency. The effectiveness of its ability to produce a clicking sensation has been also proven.

Future work involves improving the performance and usability of the Ubi-Pen. To make the interface as stand alone system, a processor and power controller should be embedded into the pen. An integrated controller for 9 actuators is being customized now and the size of its primary version is smaller than 150x18x5 mm. Power will be supplied 7.4V battery and a small processor module including more than 20 IO channels and wireless communication will be embedded in the future. Furthermore, we are trying to make the Ubi-Pen a general communication device in itself as well as an interface to other devices. We are considering new applications for this device.

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