Haptic Feedback for Pen Computing: Directions and Strategies

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ABSTRACT

We seek to improve the experience of using pen computing devices by augmenting them with haptic, tactile feedback displays. We present the design of the haptic display for pen computers, and explore interaction techniques that allow users to *feel* GUI elements, textures, photographs and other interface elements with a pen. We discuss research directions in haptic displays for pen devices and report results of an early experimental study that evaluated the benefits of tactile feedback in pen computing.

Author Keywords

pen input, haptic feedback, experimental studies, Fitt's law

ACM Classification Keywords

H5.2. [Information interfaces and presentation (e.g., HCI)]: User interfaces – Graphical user interfaces (GUI), Input devices and strategies, Interaction styles, Screen design.

INTRODUCTION

Pen-based and tablet computers are becoming increasingly popular in home, businesses and industrial use. They are attractive because of their intuitive interaction style. Instead of using indirect devices such as a mouse, the user can use a pen to push graphical buttons, drag sliders, write and sketch directly on a screen, just like on a piece of paper. Furthermore, recently implemented in the form of tablets, pen computers are compact and easy to use.

Although the history of pen input stretches back as far as the RAND tablet, developed in the 50s [10], until recently pen-based devices were used mostly by users of computer graphics systems: designers, artists and architects. Recently, however, the variety and availability of devices that support pen input have grown with introduction of PDAs and tablet PCs. With further improvement of technology, the popularity of pen-based computing will certainly continue to grow in the future.

We seek to improve the experience of using pen devices by augmenting them with haptic and tactile feedback. The problem of lack of haptic feedback when interacting with touch and pen devices was noted by Buxton as early as 1985 [5]. The sense of touch plays a crucial role in our interaction with the physical world, as it allows us to perceive object textures, recognize shapes and objects by touch, and allows for effective blind manipulation. As a familiar example, we can drink coffee while reading a newspaper, operating the coffee cup largely by touch.

We aim to investigate how these powerful haptic processing capabilities can be used to enhance interaction with pen computers. We present the design of the tactile display for pen computers, interaction techniques and results of an early experimental study that evaluated the benefits of tactile feedback in pen computers. We also discuss the directions and strategies for future exploration of tactile feedback in pen devices.

BACKGROUND AND PREVIOUS WORK

Pen interaction is similar to touch screen interaction. However, pen input covers a wider range of devices, since it can be used both with touch screens and specialized pen input devices, such as Wacom™ interactive pen displays. The pen is very effective when fast, fluid and high precision two-dimensional input is required. Therefore artists and designers often use pen-enabled displays in painting and 2D layout applications. Pens are also used in mobile devices, such as tablet computers, as a replacement for keyboard, or with PDAs, where pen allows effective interaction despite their small screens.

Figure 1: Prototype of tactile pen computer

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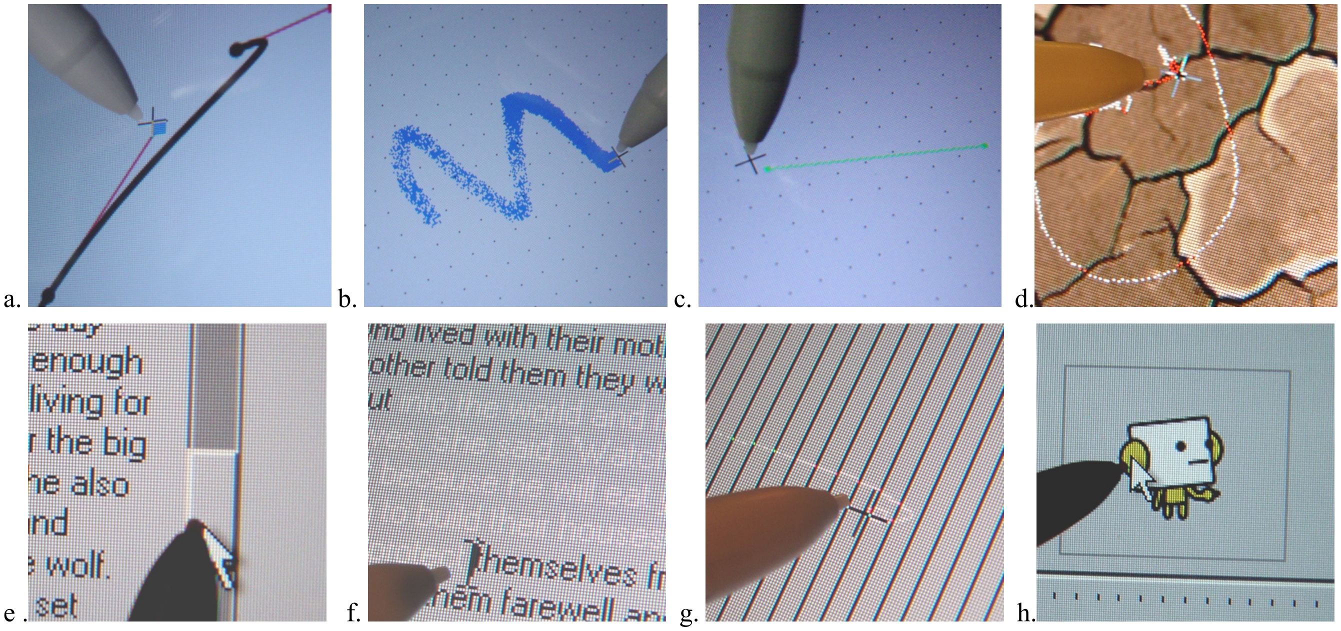

Figure 2: Pen interaction were extended with tactile feedback

There have been few attempts to combine a pen with haptic feedback devices. For example, pen-style force-feedback displays have been used for virtual reality interaction [4] and to simulate a feel of real brushes in paint programs [3]. Unlike this work, we focus on designing tactile interfaces for everyday tablet and pen computers, rather than 3D user interfaces or stand-alone haptic interactive systems.

Active Click [7] was the earliest reported tactile interface for touch screens that could also be used with a pen. Its off-the-shelf coil-type actuators, however, were too large for thin tablet devices and its tactile vocabulary was limited to a narrow range of vibration frequencies. Our tactile display provides for independent control of vibration amplitude and frequency. This allows for an infinite variety of tactile feelings for various GUI elements and interaction scenarios.

We are not aware of previous work that systematically investigated tactile interfaces for pen computers. For desktop interaction, haptic mice have been developed either by adding a solenoid [2], voice coils [9] or motors [1]. In contrast, our work investigates haptic feedback for pen-based devices that are operated without a mouse.

This project is part of a long-term research effort that investigates haptic displays for everyday devices using the TouchEngine™ tactile technology that we have developed [13]. Previously, we focused on small handheld computers. For example, [10] reports the design of "full body" tactile displays for handheld devices that provide expressive ambient tactile notifications to mobile users. In [11] we enhanced PDA touch screens with tactile feedback, so that users can feel basic GUI elements, such as buttons and sliders. This paper further develops this direction of research.

HAPTIC FOR PEN COMPUTERS

TouchEngine actuators were embedded into a stationary 15 inch LCD monitor of Sony VAIO LX personal computer (Figure 1) that has Wacom pen-input technology built into the display. We then enhanced 2D pen interaction techniques, such as GUI and drawing, with tactile feedback and informally evaluated these enhancements by demonstrating them to colleagues and visitors. Finally, after refinement, we conducted experimental studies that investigated the effect of tactile feedback in pen tapping and drawing tasks.

Haptic display for pen

We used TouchEngine haptic feedback technology to add haptic response to the screen. TouchEngine is comprised of thin custom-built piezoelectric actuators, control hardware, and software. It is described in detail in [11, 12]. The basic display design used here is identical to [11], except that larger (30×5mm) actuators were used. Here we provide only the most basic information on the design.

Four TouchEngine actuators are embedded in the corners of display in between the LCD and the thin protective glass panel on top. We attached the glass panel to the base with thin silicon adhesives that let it move slightly, but kept glass safely attached to the base. When the piezoelectric actuators bend in response to the electrical signal, they push the glass outwards and the user can feel vibration through the pen which is touching the screen. The amount of bending is proportional to the signal amplitude that is generated by the TouchEngine control board. Currently, we are using the simple pulses of different intensities.

Pen-based haptic interaction

We explored three strategies for tactile interaction with pen computers: tactile *GUI*, tactile *information perception*, and *tactile feedback for active input*. This section discusses several simple examples of tactile interfaces that we developed and informally evaluated.

GUI interaction

We added tactile feedback to GUI elements, such as graphical *buttons*, so that they would "click" when user pushed them, *sliders*, that provided a short tactile impulse each time the user scrolled a line, and *text*, where selecting a character was enhanced with a tactile click (Figure 2e, f). In informal evaluations, the users were very positive about tactile feedback. We observed that users strongly preferred tactile feedback when it was combined with a *gesture*, e.g. dragging sliders or selecting text. This preference may be explained within Gibson's active touch paradigm [8].

Feeling data

Tactile display may allow the user to feel *visual data* via the cutaneous sensory channel (e.g. feeling bumps when drawing across simple textures with a pen, or feeling cracks in the photograph of a desert). This is similar to how we can feel physical textures in the real world (Figure 2d, g). We also added tactile feedback to character animation. When the user touches a character with the pen, the animation is triggered and the user can feel the character motion; similar to how we can feel a pulse beating in a hand (Figure 2h).

The users reacted positively to these interfaces by saying that the feelings were very natural and enjoyable. We found, however, that increasing the complexity of textures *seemed to reduce* the effect of a haptic feedback and in even some case made interaction more confusing. We hypothesize that with complex visual textures the users could not easily correlate the image and tactile feedback, particularly when they draw quickly and the latency of pen input was evident. Designing tactile interfaces for data perception, therefore, is not straightforward. Spatial and temporal correlation between visual and haptic feedback in dynamic gestures must be explored in more depth. Techniques to cope with lag are also very important. One technique is to pre-compute several tactile maps for different speeds of pen movement and use them instead of the original image for triggering tactile events.

Tactile feedback for active pen input

There is an inherent sense of satisfaction when drawing with a pen or pencil. The feel of the paper, as the pen tip moves over it, creates the inherently physical and intimate feeling of drawing. Our discussions with artists and designers suggest that this physicality assists the artist's creative process.

We added tactile feedback for *drawing and sketching* operations by having a single tactile pulse produced each time the pen crossed a pixel (Figure 2b). The strength of the pulse was correlated with the pen pressure so that stronger pressure resulted in stronger tactile feedback. We also explored tactile feedback in *vector-style graphics manipulation* (e.g. feeling control points on the Bezier curve (Figure 2a)). Indeed, in complex drawings the density of control points is often very high and tactile feedback might be useful for improving selection precision. Finally, we combined tactile feedback with *constraints* such as grids and alignments. In one example, the user would feel the underlying grid while manipulating a line's endpoint in snap-to-grid mode (Figure 2c).

Active input enhanced with tactile feedback was most appreciated by the users. In particular, haptic constraints were met with delight, as they felt similar to a pen hitting a physical groove or guide. Combining constraints with tactile feedback in pen computing is an interesting direction for further exploration. Even though users enjoyed tactile feedback during the drawing task, the tactile sensation was not similar to the feel of real pen and paper. We also observed that since vibration frequency depends on drawing speed, rapid gestures were uncomfortable when the vibration became too strong. The user appreciated softer, gentler tactile feedback more. Factoring gesture speed into the design of tactile feedback is essential in creating efficient and enjoyable user interfaces. At this point, we have a limited understanding of the relationship between gesture speed, tactile feedback and resulting user experience. Finally, we observed that all users universally liked having feedback strength change in proportion to the pen pressure.

EXPERIMENTAL EVALUATION

Tactile feedback opens a new interface design space and before embarking on its exploration, we wanted to understand benefits of the tactile feedback in pen interaction and its most promising areas for investigation.

Tasks and experimental design

We designed experiments according to the ISO 9241 Part 9 [6] that is based on Fitt's experimental paradigm. Two tasks were evaluated. First, in the *tapping task*, the subjects repeatedly tapped on strips of width W separated by distance A. The target was indicated by blue color. In the tactile condition, a tactile pulse was provided when the target was successfully selected versus no tactile feedback in the normal condition.

Second, in the *drawing/dragging* task, the subjects drew a line with a pen from a starting point to the target stripe. To accomplish the task, the subjects had to release the pen within the target stripe. We studied three conditions: *normal* (i.e. no tactile feedback), a *single-impulse* feedback when the user crossed the target strip edge, and *continuous feedback* (i.e. after the pen entered the target strip, a pulse would be provided for each pixel the pen crosses, resulting in continuous tactile feedback to pen movement).

Following [6], we used 2, 5 and 10 mm target widths and 40, 80 and 160 mm distances between targets. Twelve male subjects 24 to 34 years old were recruited from the laboratory pool. A within-subject, repeated-measures experimental desugn was used where each subject completed 10 trials for each width/distance combination, resulting in 90 trials for each experimental condition. The order of conditions and trials were randomized. The experiments started with training and finished with a questionnaire to evaluate subjective preferences. The survey asked the participants to rank conditions using the Lickert scale ratings from 1 (worst) to 5 (best). Each experiment took about 40 minutes. The next section presents the main results of the experiments.

Experimental procedure and results

Tactile feedback did not improve the user performance in the *tapping task* since mean completion times were almost identical for 5 and 10 mm targets. There was some variability for 2 mm targets, but it was not statistically significant

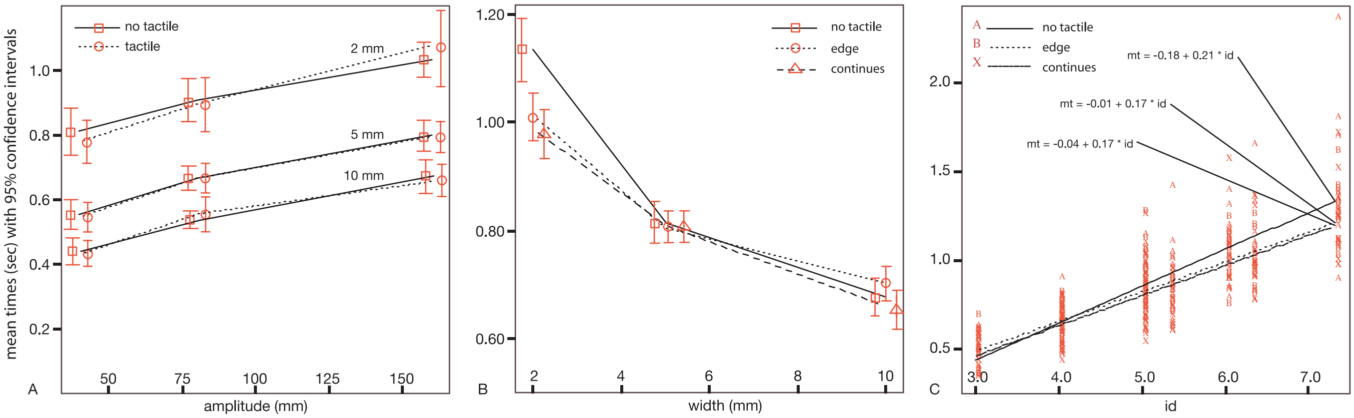

Figure 3: Experimental results: a) mean times in tapping task; b) mean tines in drawing task collapsed across amplitude c) scatter plot of time versus Fitt`s index of difficulty with linear regression lines for different tactile conditions

with the number of subjects we tested (Figure 3a). Bandwidth, estimated using Fitt's law, was identical in tactile and normal conditions — 7.14 bit/sec. We observed that subjects often hit the target rather then touch it. hence the contact between the pen and screen was very short. In fact, during the training, some subjects initially did not even notice the tactile feedback. Feedback had a greater impact for small targets, where size forced subjects to tap slowly. The effect of feedback in selecting very small targets could be an interesting future research direction.

Tactile feedback improved user performance in the drawing task by a statistically significant amount. There was significant interaction between feedback, amplitude and target width and the effect of feedback was strongest for smaller targets (Figure 3c). The subject was about 18% faster for 2 mm targets when averaged across all distances. Assuming that the dragging falls under Fitt's law [6], the bandwidth could be estimated as 5.9 and 4.8 bit/sec for tactile and no tactile conditions respectively. Figure 3b demonstrates that as the difficulty of task increases the benefit of tactile feedback over no feedback conditions increases. We were surprised to find that the two modes of feedback that we studied resulted in almost identical performance. This indicates that just providing tactile feedback on the target boundary might be sufficient, although subjects preferred continuous feedback (4.2) to the feedback on the edge (3.5).

The experimental results suggest that the combination of active gesture with tactile feedback yields significantly better results then for the simple tapping task. This is also supported by the survey of the users' subjective preferences. On average, subjects rated tactile feedback in the drawing task as 3.9 versus 2.5 for no feedback on a 1 to 5 scale. In the tapping task the ratings where 3.4 and 2.4 respectively.

We believe that these tasks and conditions approximate a bulk of the interactions in pen computing (i.e. selecting targets of various sizes separated by differing distances, dragging icons and scroll bar handles). Therefore, the results of the experiments can be generalized to traditional GUI applications.

CONCLUSIONS

We presented an overview of haptic interfaces for pen computing, a new area for interaction research. The most basic interaction scenarios have been discussed, prototyped, and evaluated. The experiments that we conducted demonstrated the value of tactile feedback and indicated directions for future improvements and investigations. In the future we will conduct more extensive experimental evaluation in order to confirm the reported experimental results.

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