MicPen: Pressure-Sensitive Pen Interaction Using Microphone with Standard Touchscreen

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Abstract
This paper introduces MicPen, a low-cost pressure-sensitive stylus pen interface for standard touchscreen displays that uses a microphone to estimate the amount of pressure applied to the pen. This is achieved by filtering and analyzing the acoustic signal generated when the tip of the pen is rubbed on the touchscreen. The advantage of this approach is that it is inexpensive, reliable and suitable for mobile interaction because it does not require mechanical parts to sense the input pressure. Results from a user study shows that the participants recognized five out of ten different pressure levels with perfect accuracy, and nine out of ten with minimal error.

Keywords
Tangible User Interface; Pressure Input; Haptics

ACM Classification Keywords
H.5.2. [Information Interfaces]: User Interfaces—interaction styles; input devices and strategies; haptic i/o.

General Terms
Design, Human Factors

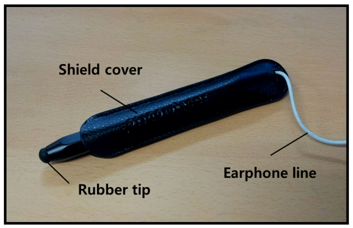

Figure 1. The MicPen prototype.

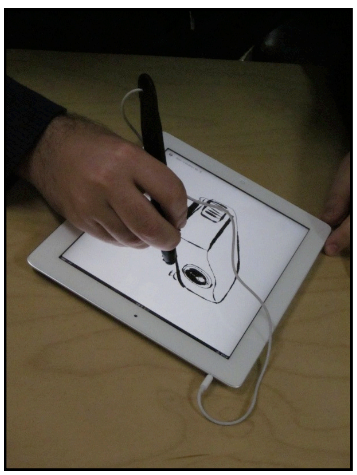

Figure 2. Drawing with the MicPen interface.

Introduction

Portable touchscreen devices such as the popular iPod and iPad by Apple have become widely adopted worldwide because they support multi-touch and gesture interaction techniques that are intuitive and easy to use. These devices not only have attracted a new category of users that were not familiar with traditional desktop computers [e.g., 1], but also have sparked new possible area of research aimed to make such interaction more realistic, like augmenting it with a layer of tactile sensations (e.g. Teslatouch [2]).

In particular, researchers have shown that the combined usage of direct touch and pen-based input techniques on capacitive screens has great potential [3, 6], as this simultaneous interaction is faster and more accurate than not when using any of the two techniques separately [3]. However, despite the potential of the combined usage of pen and touch, pen-based interfaces are rarely used in commercial products mostly because they are either passive pressure-insensitive tools (e.g. standard capacitive pen), or require specialized and expensive hardware that is not suitable for mobile interaction (e.g., need for special pens [8, 12] or special displays [9, 11]).

In this paper we present MicPen, a novel pen-based input technique for out-of-the-shelf capacitive touchscreens, specifically indicated for portable devices, that is reliable, cheap and does not require mechanical hardware to sense pen pressure. Similarly to previous work that uses sound to infer input gestures [4, 5], the MicPen captures with a microphone the audio generated by the tip of a stylus pen when dragged on a display, and uses it to determine the pressure applied.

The rest of the paper introduces the MicPen interface and describes the technical novelty and benefits of this approach; in the second part of the paper we present the results of a study designed to test the accuracy of MicPen, and indicate future avenues of research.

Related Work

Researchers have proposed two approaches to detect the pressure applied with a pen or a stylus when drawing on a capacitive screen. The first method requires the customization of the pen with mechanical parts, such as pressure sensors [8], electromagnetic solenoid coils [12], or encoders (like the Phantom haptic device [10]). In all these cases, the pen can sense the pressure with high accuracy and reliability, but it also requires a physical customization to accommodate a power source, additional mechanical hardware and a control circuit. Because of these technical requirements (which usually translates in higher hardware costs and pen size), this solution was often considered as impractical for real usage.

A second approach leaves the pen interface unchanged, but requires modifying the sensing surface that is in contact with the pen. By creating a grid of optical or capacitive sensors [11], or by modifying the whole touch sensitive device which receives the input [9], the technical equipment and complexity necessary to sense the pressure are shifted from the pen to the drawing surface. The drawback of this approach is that modifying the sensing surface is more expensive than modifying the pen, and the system is usually not suitable for mobile interaction because of its size [9].

The technique we propose in this paper is based on the analysis of the acoustic information that is generated

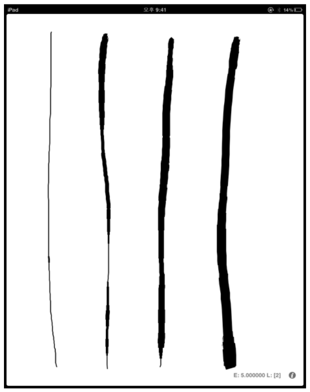

Figure 3. Line with different thikness generaged when applying varying pressure.

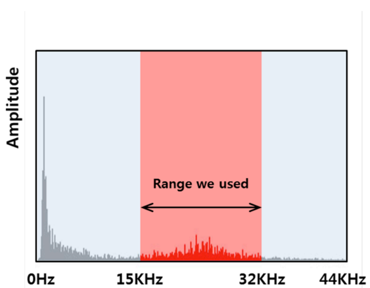

Figure 4. Graphical representation of the 15-32 KHz range considered for estimating the pressure.

from a microphone positioned inside a standard pen for touchscreens. By analyzing the different frequency components of the sound produced by the tip of the pen when drawing, we are able to infer the amount of pressure applied. Such technique is similar to the one proposed by Harrison et al. [4], in which different hand gestures are recognized by sensing the acoustic information that fingers generate when scratching on a surface monitored with a microphone. More recently, an extension of this work was proposed [5], in which the interface can also detect what part of the finger is in contact with the surface. Our work extends this technique by applying it to a novel pen interface in order to estimate the pressure applied.

Sound-based Pressure estimation

MicPen (Figure 1) is a pressure-sensitive pen interface obtained by placing a microphone in a standard stylus for capacitive screens. When the rubber tip of the pen is dragged on the glossy display, the friction produces a sound that is easily captured by the microphone and used to estimate the amount of pressure applied with the pen. MicPen, differently from previous works, senses the amount of pressure without the need for custom mechanical hardware (e.g., sensors or encoders), and is a simple, cheap and reliable interface suitable for mobile interaction (microphones are smaller and more robust than pressure sensors because of the lack of movable parts).

Implementation

Hardware Prototype

Figure 5 shows the schematic overview of the MicPen prototype. We modified an out-of-shelf stylus pen with a conductive rubber tip designed for capacitive sensing

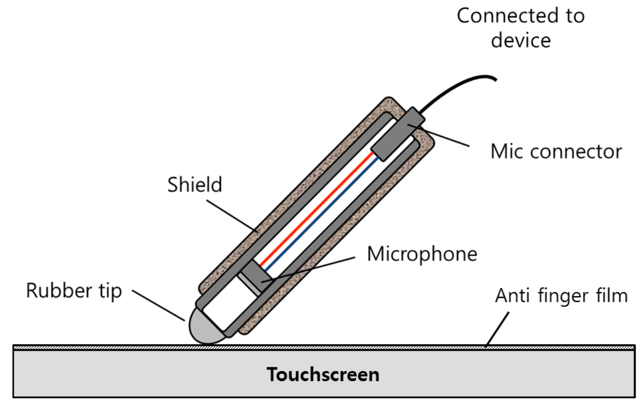

Figure 5. Schematic overview of the MicPen prototype and its components.

touchscreens. We then placed a cheap electric condenser microphone (~2 US$) in the body of the pen and a thin 3M Estoc Plus anti-finger glossy protection film (~15 US$) on the top of the iPad display to increment the friction between the rubber tip of the pen and the surface of the display. This film was chosen among several candidates through empirical exploration. The microphone was connected with a wire to the standard 3.5pi audio jack of the iPad, and the pen was finally covered with a layer of leather to improve ergonomics and reduce acoustic noise from the environment.

Pressure Estimation Algorithm

When the tip of the MicPen is dragged on a glossy display applying varying pressure, the rubber tip is compressed changing its diameter from approximately 1mm (low pressure, empirically measured as ~0.015 Kg) to 8 mm (high pressure, ~0.09 Kg). When the tip of the pen is moved, this compression produces as consequence acoustic sound with different frequency values in the range 15-32 KHz (Figure 6). Analyzing such sound allows to estimate the amount of pressure applied to the stylus.

We developed a software for Apple iPad2 with iOS 5 using the Apple SDK and the Fmod library (www.fmod.org) for computing in real-time a Fast Fourier Transformation (FFT) on the incoming audio signal. Our software receives the sound captured by the microphone inside the pen and computes an FFT using a non-overlapping rectangular window sampled at 44 KHz. Then it filters all the frequencies outside the range 15-32 KHz to block acoustic noise (e.g., voice), and samples 512 intervals at 16-bit (quantization). The software computes the sum of the amplitude values of these samples and uses it as a rough estimation for pressure.

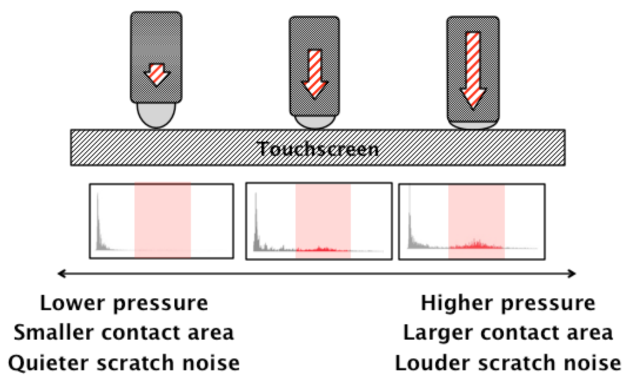

Figure 6. Graphical representation that illustrates how varying pressures generate different acoustic information.

GUI and Visual Feedback

The GUI of the software consists of a white canvas on which users can draw lines with the stylus pen. The thickness of these lines is proportional to the pressure applied with the pen (the higher the pressure, the thicker the line, as in Figure 3), and it ranges from 1 to 30 pixels (approximately corresponding to the diameter of the pen tip, from 1 to 8 mm).

To simplify the interaction, we arbitrarily constructed 10 pressure levels, each one represented on the screen as a multiple of 3 pixels (level 1 is 3 pixels wide, level 10 is 30 pixels wide) and mapped to 10 corresponding pressure levels. The pressure levels are built according to the research on Just Noticeable Differences (JND) [7], for which the average stiffness differential threshold (Weber coefficient) is 17% [7]. This means that each of the 10 pressure levels can be perfectly recognized and distinguished from the others because it has an increment of pressure of 17% over the previous level.

Feasibility Test

We designed a simple experiment to test the accuracy of users when they apply pressure to the pen. In this experiment we asked users to recognize and selectively input 10 different levels of pressure in random order, so to match those displayed on the screen. The goal of the experiment is to verify how accurate this input technique is for different pressure levels.

Participants

We recruited 10 volunteers among students and researchers, 6 males and 4 females, with age between 23 and 30 (average 26.1, SD 2.47). 50% of the participants self-reported to be advanced computer users, 30% intermediate, and 20% beginner. 90% reported to be familiar with haptic and all of them had an experience with digital drawing input devices (e.g., tablet and drawing applications).

Materials and Method

After a briefing about the experiment and collecting participant's data for demographics, the users were given few minutes to familiarize with the MicPen system before starting the experiment. For the experiment we implemented a software for the Apple iPad2 that randomly computes a pressure level among the 10 possible. The selected pressure level is then represented as a line with the thickness computed as explained before, and that runs vertically across the screen. Such line is the target and serves as a reference point in the background. In fact, users are asked to draw another line on the top of the target line, applying the amount of pressure necessary to match its thickness. When the pen is lifted from the screen, the software computes the median pressure level applied and stores it in the memory, concluding a single trial. A new pressure level is then randomly generated and displayed on the screen for another trial until all trials are completed. When all the trials are completed, the stored data is sent over a WIFI connection to an online FTP server that keeps all the data logs.

Our experiment consisted of 120 random input trials: the first 20 were discarded and considered as training, the remaining 100 (exactly 10 trials per 10 pressure levels) were used for the analysis, comparing input with target pressures. After the experiment we gathered informal feedback in a post-hoc interview. The experiment took approximately 30 minutes to complete and participants were compensated for their time.

Results and Discussion

Figure 7 graphs the pressure inputs by users for each of the 10 target pressure levels. Perfect accuracy (input pressure level is equal to target level) is obtained in the 50% of the cases, while 90% accuracy is achieved within one error level (e.g., level 2 pressure was demanded but level 3 pressure was input). Further analysis on the pressure raw data confirms that the input was highly correlated with the pressure demanded by the system (Pearson test: $r=0.94$, $n=10$, $p<0.0001$) and no significant difference was found between the two (paired t-test not significant $p=0.84$).

Although this study has clearly revealed that MicPen is a very accurate pressure input technique, we also found a technical glitch. In fact, most users failed to input high pressure levels (i.e., level 10). In the post-hoc interview users revealed that, although they were able to recognize what pressure level the system asked for, they were not able to input it. In fact, we found that after a certain threshold (around level 8) input pressure was not correctly computed, because the

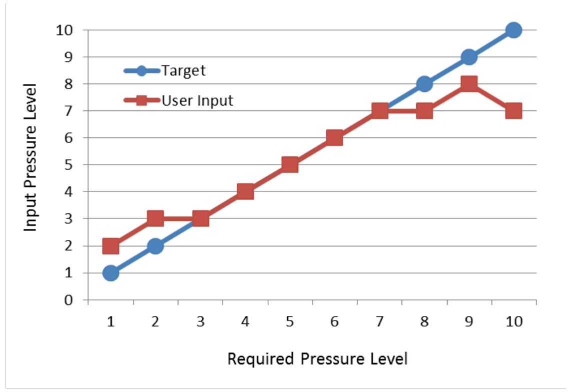

Figure 7. Graph of the accuracy level achieved with MicPen.

sound generated by the tip of the pen was attenuated and was hence not proportional to the pressure applied. Despite this glitch, which could be solved in further versions of the system, we found that users could easily distinguish and select different input pressures.

Conclusion and Future work

In this paper we presented MicPen, a novel pressure-based pen interface for conventional touchscreen displays that captures with a microphone the sound generated by the tip of a pen when rubbed on a device screen and uses it to estimate the amount of pressure applied. Through a prototype and a user study, we showed that the idea is feasible to use, as users can accurately distinguish nine of ten pressure levels with a minimal error.

Several avenues of research are possible for extending this work. The possibility consists in exploring variations of the pen interface (e.g., the tip of the pen could have different shapes and sizes; replacing the external microphone with one embedded in the screen) or exploring different application scenarios. In fact, MicPen is suitable for drawing applications but could also be used as a substitute for mouse or joystick interaction, as it offers an easy way for selecting among different options (ten distinguishable pressure levels). Finally, it would be interesting to test the MicPen interface with a professional artist in order to gather feedback about the ease of use and expressiveness of this interface for drawing.

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