PENny: An Extremely Low-Cost Pressure-Sensitive Stylus for Existing Capacitive Touchscreens

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ABSTRACT
By building a wired passive stylus we have added pressure sensitivity to existing capacitive touch screen devices for less than \$10 in materials, about 1/10th the cost of existing solutions. The stylus makes use of the built-in audio interface that is available on most smartphones and tablets on the market today. Limitations of the device include the physical constraint of wires, the occupation of one audio input and output channel, and increased latency equal to the period of at least one audio buffer duration. The stylus has been demonstrated in two NIME applications thus far: a visual musical score drawing and a singing synthesis application.

Keywords
input interfaces, touch screens, tablets, pressure-sensitive, low-cost

1. INTRODUCTION
The growth of increasingly powerful mobile devices have provided a new platform for the implementation of NIMEs [8]. The opportunities provided by mobile devices lie not only in the processing and multimedia capabilities, but also the wide potential user base due to the ubiquity of such devices.

However, one area of limitation for mobile devices, especially for NIME, lies in their input capabilities. The primary form of input on such devices is the touch screen. While the act of drawing and writing is an expressive medium of expression that has been used throughout history, most modern devices do not adequately simulate the experience. Drawing and writing is implemented through the detection of finger or stylus position on a sensing display, but most devices do not capture the pressure information, a crucial component of the process that every person learns from a young age. Only a small portion of devices on the market today integrate pressure sensing technology into the display[1]. While developing new instruments on mobile devices, we have devised an extremely simple pressure sensitive addition that makes use of as much existing hardware as possible, thereby reducing the cost and number of new components used.

2. RELATED WORK
The Melody Easel from the Brain Opera [9] is one of the earlier examples of an existing display augmented with location and pressure sensitivity for gestural control of music. The Wacom digitizer [3] consists of an inductively powered active stylus with sensing circuitry that transmits pressure information wirelessly to the receiver circuitry. It has been used as an expressive musical controller on a number of occasions [12] [6] [5]. [11] is an example of a physical interface that detects multiple pressure points and widget location and orientation. While the interface allows a richer set of inputs to be captured, the active electronics and components add to the bulk and cost of the device.

A number of manufacturers have addressed the lack of pressure sensitive touch displays on modern devices through the implementation of active (powered) pens and styluses. The Adnoit Touch [1] is an example of a pressure sensitive pen designed to be used for bluetooth enabled devices. An active pressure sensing circuit is built into a pen package with a conductive tip to detect the pen's location on screen. The analog to digital conversion is performed by the onboard electronics, and then sent to the host device via bluetooth.

The Hex3 Jaja [7] pen is an active device that emits a human-inaudible analog tone that varies according to the pressure applied. The audio signal is picked up by the microphone input on the host device and decoded into pressure levels. By eliminating a digital wireless connection the circuitry inside the pen is reduced. One of the major limitations of the device is that since each pen radiates the same tone, multiple pens cannot be used in close proximity with each other without interference. Additionally, perhaps ironically, the cost of this pen is the same as the Adnoit Touch mentioned above at around \$90 despite the lack of digital transmission circuitry.

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[1]Samsung Galaxy Note and Microsoft Windows Pro Tablets, for example.

3. SYSTEM OVERVIEW

PENny is a pressure sensitive stylus for a smartphone or tablet device. PENny uses a similar concept of using audio signals to represent pressure data as the Hex3 jaja [7], but with an additional simplification: even the production of audio is done by the parent device, and as such no active circuitry is required at all, eliminating most of the circuit components, the need for batteries and drastically reducing cost. Additionally, the wired interface eliminates the possibility of wireless interference and multiple pens can be used within close proximity.

3.1 Hardware

The central component of the PENny system is a passive resistor network wired to the mobile device's audio input and output ports. The resistor network consists of a fixed and variable (sensing) resistor set up in a voltage divider configuration as shown in Figure 1 and is fed with an audio signal from the device through the network at V_{in}, the output at V_{out} is dependent on the value of R_2 given by Equation 1.
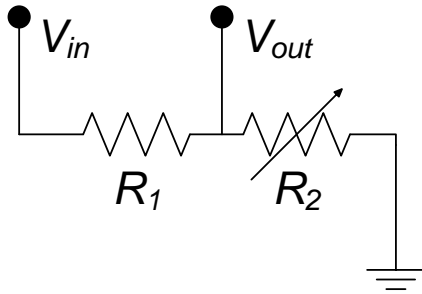

Figure 1: Two resistors in a voltage divider configuration

$$V_{out} = V_{in} \times \frac{R_2}{R_2 + R_1} \tag{1}$$

If the resistor R_2's resistance changes with applied pressure (such as a flex or force sensor), the output voltage will change as well and this corresponds to the force applied. For the first prototype, we have placed a force sensitive resistor (FSR) on the tip of a conductive tube [2] cushioned with a small piece of foam. A strip of copper tape was placed over the outer surface to ensure conductivity for the capacitive sensing of XY location (touch). Since most audio circuitry is DC filtered (to prevent a constant voltage offset from damaging speakers), we choose a sinusoidal signal as the input activation. A diagram of the hardware layout is shown in Figure 2 along with a photo of the prototype.
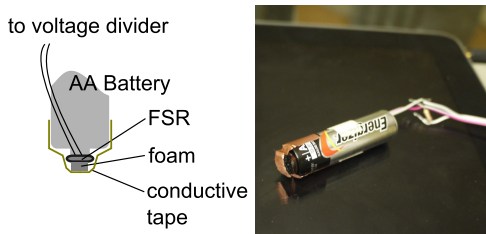

Figure 2: PENny Hardware Layout

The total cost of the materials, using readily available components from an electronics store at retail price, is un-

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[2]A used AA battery was employed in this case

der \$10 (Compared to around \$100 for styluses with active electronics). Table 1 shows a cost breakdown of the device.

Table 1: Cost Breakdown of the PENny Stylus

ITEM	COST
FSR	\$5.95
4-pole 3.5mm Plug	\$1.50
10k Resistor	\$0.15
Wire	\$0.10
Conductive Tube	\$0.50
Scrap foam	\$0.10
5cmx5mm Copper Tape	\$0.15
Total	**\$8.45**

3.2 Software

In terms of software, the application responsible for pressure sensing has to generate an audio signal to the sound card and then receive it. The power of the received signal can be calculated to determine the force applied. The audio system runs at 44.1kHz with a buffer size of 512 samples (11ms). The excitation signal is a sine wave generated at 8Khz. We take the power measurement of the received buffer from the audio input, and run a moving average of 4 buffers for smoothing. The software is implemented using openFrameworks [2] which allows applications to be compiled for all iOS devices with audio in and out capabilities.

4. APPLICATION EXAMPLES
4.1 Portable Vuzik

Vuzik is an interactive, visual musical score interface [10]. Originally implemented on a large screen display augmented with drawing input, Vuzik allowed the creation of a score through painting gestures. While the large screen allowed larger arm movements, the system required specialized hardware and was not readily available to the public. We are interested in exploring the use of the visual drawing metaphor on smaller and more accessible devices such as the iPad. While the level of precision on a smaller screen may be lower, the sheer number of devices on the market allows the system to be deployed to a larger audience. We have begun porting the application into iOS/openFrameworks and hence it was easy to provide a proof of concept using the PENny stylus as input. In Vuzik, the thickness of the drawn lines represent note velocity and due to the lack of pressure input, this parameter had to be selected using a menu. By mapping the line thickness to the input pressure, not only is it more convenient and intuitive (consistent with the painting metaphor of thicker lines equating to brush stroke pressure), the pressure to line thickness mapping also eliminates the need for extra UI widgets that take up screen space.
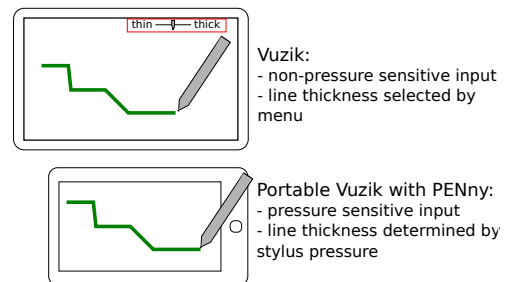

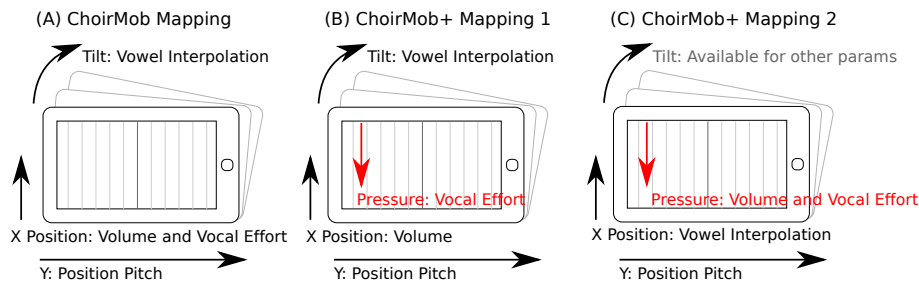Figure 3: PENny as Input for the Mobile Vuzik Prototype

(A) ChoirMob Mapping   (B) ChoirMob+ Mapping 1   (C) ChoirMob+ Mapping 2

Tilt: Vowel Interpolation   Tilt: Vowel Interpolation   Tilt: Available for other params

Pressure: Vocal Effort   Pressure: Volume and Vocal Effort

X Position: Volume and Vocal Effort   X Position: Volume   X Position: Vowel Interpolation

Y: Position Pitch   Y: Position Pitch   Y: Position Pitch

Figure 4: ChoirMob and ChoirMob+ Mappings

4.2 ChoirMob+

ChoirMob is an iOS-based singing synthesis application [5] and is based on the HandSketch instrument [4] that used a Wacom Tablet an input controller. When moving the interface onto a smaller screen without pressure sensitivity, sacrifices were made including the reduction of pitch range and the remapping of volume/vocal tension to one of the touch screen axis, thereby occupying one of the position axis that was originally used for vowel mapping. A less precise vowel interpolation was assigned to the tilt angle of the device. We have developed ChoirMob+ with the addition of the PENny stylus that brings back pressure sensitivity into the system. We are experimenting with reimplementing the vowel mapping and comparing that with the decoupling of volume and vocal tension parameters and opening up the tilt to control other vocal parameters, as shown in Figure 4. While a smaller capacitive touch screen does not provide the same degree of precise control as a Wacom tablet, the size and ubiquity of portable devices allow new opportunities for exploration.

5. LIMITATIONS

The PENny stylus requires the use of the audio jack, which disables the internal speakers of the device and occupies one audio input and one audio output. If the remaining channel of audio output is required by the application, the extra channel can be broken out from the stylus through a separate jack, but only external speakers can be used. In general, since the built-in speakers on portable devices require amplification in most performance settings, this constraint is not unreasonable.

Compared to wireless styluses, the wired device does constrain movement in return for the extremely simple design. Another potential issue is input latency introduced by the audio input/output system. Since the sensing of the pressure requires both the transmission and receiving of audio, at least one additional buffer period is added to the process.

6. CONCLUSION

By using a passive stylus driven by the built-in sound card we have demonstrated the possibility of adding pressure sensing capability to a large number of tablets and smartphones at less than 1/10 the cost of existing solutions. The wired interface dramatically reduces the cost of the design through sacrificing an audio input/output and some freedom of movement. However, as an input interface it is an extremely simple way to add pressure sensitivity and can provide more expressive input suitable for NIME as well as other artistic applications, especially for the casual end user where many mobile apps are targeted. The interface has been used in two application examples to demonstrate its effectiveness. We hope that this method can be used by the community to extend the functionality of existing devices for creative applications in a simple, cheap and efficient manner.

7. REFERENCES

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