TouchEngine: A Tactile Display for Handheld Devices

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ABSTRACT

In this paper we describe the design of a haptic display for mobile handheld devices, including the development of a new miniature actuator, the construction of a haptic display using this actuator and prototypes of early applications.

Keywords: tactile feedback, mobile devices and interfaces

INTRODUCTION

The feel of touch is crucial in our interaction with the physical environment. Twenty times faster then vision, with a 10kHz bandwidth, touch allows us both to perceive the minute material properties of everyday objects and manipulate them with amazing precision and speed [6]. For example, when we rapidly roll a pencil between our fingers we rely solely on the feeling of touch to dynamically readjust the grasping forces and fingers position. The importance of the tactile feedback in designing user interfaces has been recognized in a variety of fields from virtual reality [3] to design of consumer electronics [5].

Handheld devices, such as mobile phones, PDAs, and pagers could benefit greatly from tactile interfaces. It is difficult to design effective user interfaces for these devices because of their small size, low-resolution screens [4], and limited input capabilities [2]. Tactile displays can provide an additional, highly effective channel of communication that allows the users to "feel" the information inside of the devices and manipulate it more effectively.

TOUCHENGINE: MOBILE HAPTIC DISPLAY

One of the challenges in bringing tactile feedback to handheld devices is developing suitable haptic actuators - transducers that convert applied electrical signal into physical motion. The optimal actuators should: 1) have small, miniature size 2) be lightweight 3) use low voltage (~5V) and power 4) have low latency (~5ms) 5) produce a variety of tactile patterns with different frequency and amplitude 6) provide enough force 7) be easy to customize to allow retrofitting to devices of various sizes and forms.

We are not aware of any current actuators that satisfy these requirements. Some mobile phones use motors to rotate an eccentrically weighted shaft and vibrate. However, their latency and response time is very large, so they are not suitable for interactive applications. Fukumoto [1], recently used voice coil type actuator in his Active Click interface - the first interface to introduce mobile tactile feedback. However voice coils can only show a single frequency of vibration and its force-to-size ratio is very small, so they may not be suitable for many handheld haptic applications.

The TouchEngine Haptic Actuator

The TouchEngine actuator is constructed as a sandwich of thin (0.28μm) piezoceramic film with adhesive electrodes in between, resulting in a thin (0.5mm) beam (figure 1b,c). The piezocermic material works as a solid state "muscle" by either shrinking or expanding depending on the polarity of the applied voltage. The material on the top has an opposite polarity to that on the bottom, so when a signal is applied the whole structure bends (fig. 1a). This configuration is, therefore, often called a "bending motor" actuator.

The bending motors that currently exist consist of only two layers (biomorphs), require a minimum of ±40V for bending, and produce a low force, making them unsuitable for the mobile devices. However, by sandwiching multiple layers of the piezzo material with electrode layers, we can reduce the voltage required for maximum displacement to ±8-

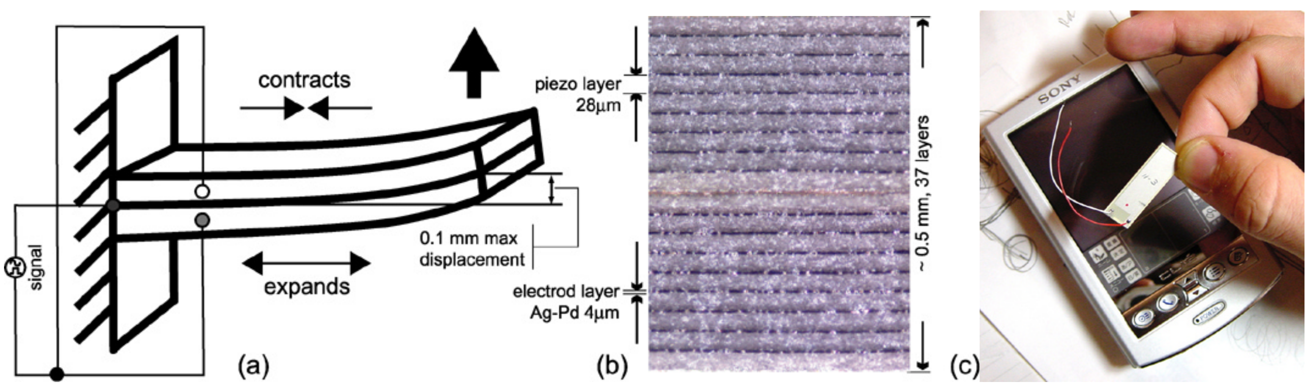

Figure 1: (a) The actuator: the top layers contract and the bottom expands, bending the entire actuator. (b) A microscopic view: 18 layers of piezzo and 19 layers of the electrodes; (c) the actuator; 30 mm long, 8 mm wide and 0.5 mm thick.

10V. For voltage V and thickness T, the displacement D and force F for the bending motors are:

$$D = a_1 \cdot V / T^2 \text{ and } F = a_2 \cdot T \cdot V,$$

where a_1, a_2 are coefficients. So decreasing thickness T we can achieve the same displacement with a lower voltage. This also decreases the force, we compensate for this by layering several thin piezoceramic layers together.

The resulting actuator has unique properties. It is thin, small, can be operated from a battery and produced in different sizes and number of layers. It is also extremely fast; accelerations of up to 5G can be produced, and we can control both amplitude and frequency to up to 10kHz.

Mobile Tactile Displays using the TouchEngine

The actuator that we designed is bent by the applied signal. The next step is to convert this mechanical motion into a force that can be felt. The major challenge in doing this is the very small total displacement of the actuator, less then 0.2 mm. Two strategies have been developed to utilize our actuator: direct haptic display and indirect haptic display.

In *direct tactile display* the actuator moves a part of the device, which can be a single button or an entire screen of the PDA. The basic interaction metaphor is direct touch. When the user touches a device element augmented with tactile feedback, various tactile patterns are communicated back, depending on the state of the interface. For example, a button on the TV remote control may feel different when the limit of the control is reached. Different elements of the device can be augmented with the different tactile feedback allowing for rich user interaction. However it is also difficult and expensive to retrofit all the elements of small handheld device with their own tactile actuators.

Indirect tactile display is based on the tool metaphor: When one hits a nail with a hammer the force is not communicated directly; we feel the effect of the impact through the entire tool. To achieve a similar effect, the actuator is placed anywhere within the device with a weight attached to it. A force is generated using conservation of momentum: for an isolated system with no external force, its total momentum is zero. Thus, when the actuator bends, the mass moves up or down with momentum p_a and the entire device moves with *equal* momentum p_d in opposite direction (figure 2). The force felt by the user is the time derivative of the momentum: faster actuator motion results in a stronger force.

With this method, the entire handheld device acts as a tactile display. Because our actuator moves very fast, we were able to create very sharp, distinct force impulses. Also, the tactile actuator can be attached anywhere inside the device making construction of a tactile display easy even for very small devices.

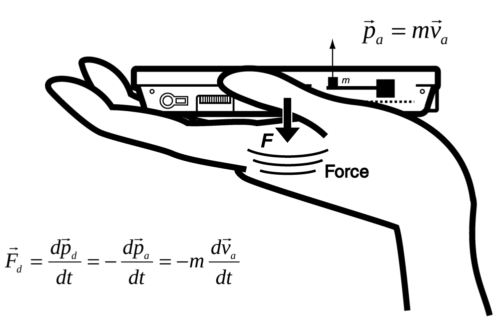

Figure 2: Indirect Haptic Display

APPLICATIONS

Two applications have been designed using TouchEngine technology. In Communication Panel the screen of a Palm compatible PDA is retrofitted with 4 actuators under the glass surface. The entire construction is only 1.2 mm thick. The aim was to provide a tactile feedback to touching the PDA display with finger or stylus[1]. In the current application, touching different interface elements results in different tactile sensations, e.g. simulating the response of a physical button. Informal trials suggest that adding tactile feedback to a touch screen may increase pointing accuracy and allow to use small PDA screens more effectively.

In another application we have augmented a PDA with a tilt sensor and a TouchEngine haptic display. A simple 2D navigation task was implemented that allows a user to navigate through a 2D subway map by tilting the PDA. The tactile display embedded into the PDA provides the user with fast haptic feedback for gestural control: as the user scrolls the map he “feels” the map shifting inside of the PDA. The TouchEngine provides a haptic display of the speed of scrolling as well as the map boundaries. All this information is communicated using tactile patterns with different rhythm, frequency and amplitude. Previous gesturing interfaces, e.g. [2], relied entirely on visual feedback, which is often too slow for precise manipulation, causing selection “overshoot”. Informally, we have found that adding tactile feedback makes it easier to precisely control the PDA with gestures while requiring less visual attention.

CONCLUSIONS AND FURTHER WORK

The small actuator we have developed allows us to build effective tactile displays for mobile devices and allow the user to ‘feel’ the information inside of the device. We are just starting to investigate the opportunities created by these new actuators, however the initial applications have developed show promising results. In the future we will evaluate the effect of tactile feedback in formal experiments and continue to explore the mobile tactile application space.

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