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Touchpad-Driven Haptic Communication using a Palm-Sized Vibrotactile Array with an Open-Hardware Controller Design

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Abstract. We demonstrate a 30-element vibrotactile array that fits the palm of a large-handed user. The array is driven by input to a touchpad, thereby allowing one user to haptically “draw” on a remote user’s hand. Pulse-width modulation is used to control tactor intensity, and the multiple intensity levels are used by an anti-aliasing procedure that allows the array to represent changes at a sub-tactor resolution and produce smoother sensations. The array includes an open-hardware controller design useful for other applications.

1 Motivation

We have developed a 30-element (5 × 6) array of vibrating DC motors to serve as a testbed for haptic display of information to a user’s palm. One application we consider is the use of the array for interpersonal haptic communication. Previous haptic devices for interpersonal communication include the ComTouch vibrotactile device for augmenting voice communication [1], the inTouch mechanical rollers that allow manipulation of a seemingly shared device [2], and the HandJive hand-held entertainment device [3], among others. Such devices can establish a sense of co-presence and communicate emotion or other information.

Our approach is to approximate the sensation of a user’s fingertip on another user’s palm, thereby allowing one user to haptically “draw” on a remote user’s hand. Figure 1 illustrates the touchpad-driven haptic communication system we have developed for this purpose. A user touches a sensing surface, in this case a laptop touchpad, that measures location and intensity of contact. The contact coordinate is mapped to the coordinate system of the palm-sized array of vibrating motors. A spatial anti-aliasing function distributes intensity among up to four nearby motors, with individual motor intensity proportional to distance from the mapped coordinate. The anti-aliasing reduces perceivable discrete changes, producing smoother sensations of motion.

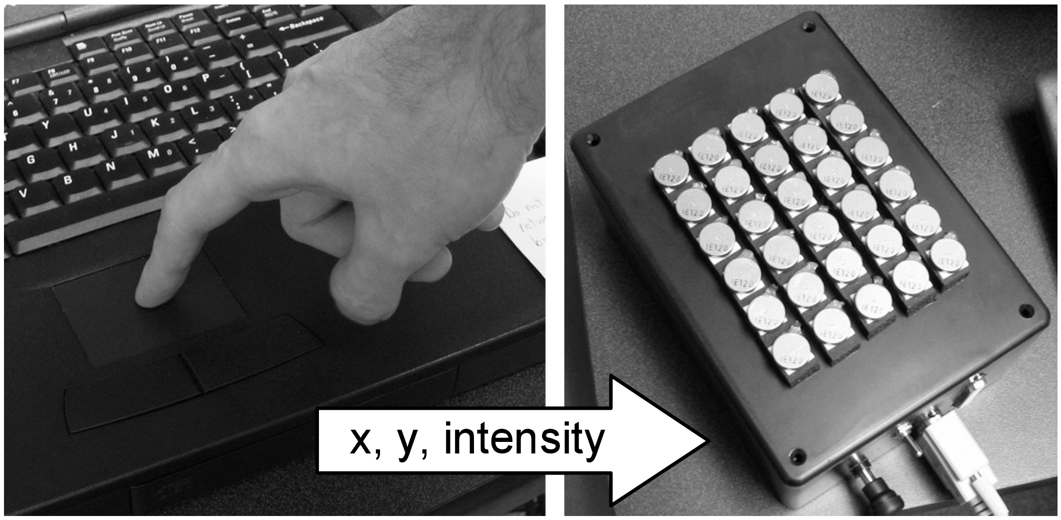

Fig. 1. Touchpad-driven haptic communication

2 Implementation Details

Our array is built from low-cost, widely-available components. Vibrating motors (Sanko Electric 1E120, diameter 1.4 cm) are arranged in a 5 × 6 grid with an inter-motor spacing of approximately 1.8 cm (center-to-center). They are mounted to a project box using foam pads to help isolate them from the box and from each other. This also allows the shape of the array to deform slightly according to the shape of a user's hand. A haptic controller is mounted inside the box. It connects to an external power supply and a standard serial cable for communication with a host PC.

Our open-hardware haptic controller, pictured in Figure 2, is a simple, compact, low-cost controller for a range of low-power DC devices. In this respect, it is similar to Lindeman's Tactaboard [4]. However, our design is simpler and is easily duplicated by others. In fact, a solderless prototype can be constructed in well under an hour using a widely-available project board. The controller is therefore especially well-suited for quickly prototyping ideas or for introducing students to haptic controllers. The design uses a Stamp microcontroller that is simple to program and interface to other devices, albeit with a limited execution speed due to its use of an interpreted BASIC-like language. Despite its simplicity, the controller is sufficiently powerful for various applications of low-power DC haptic elements. It supports independent control of up to 32 low-power DC devices and includes an adjustable on-board power section for device ratings of +1.25V to +6.75V.

The main controller components are the Parallax Stamp BS2p40 microcontroller and five ULN2003A darlington transistor arrays (these support loads up to 500mA per output and have built-in diode clamps that prevent back voltage from damaging the Stamp). Additional components consist of a KA7805 regulator for Stamp power, a LM350 regulator for motors, and a small number of capacitors and resistors.

To provide multiple intensity levels for motors, pulse-width modulation (PWM) can be performed on the Stamp or in the host driver. Due to the limited execution speed of Stamp instructions, PWM performed on the Stamp is only effective when the number of motors turned on simultaneously is small. When many outputs are controlled with independent levels simultaneously, better results are achieved by performing PWM in the host driver. In the latter case, the host driver continually sends four-byte bit-mapped commands in which each bit corresponds to the current desired state for one of the motors (on or off), and the Stamp code simply places incoming bytes into output registers. We achieve a stable PWM switching rate of about 300 Hz and currently use 23 motor levels without perceivable PWM pulses.

We have measured the fundamental vibration frequency of the array motors to range from 27 Hz to 100 Hz, depending on the choice of PWM pattern and the manner in which a motor is contacted. Higher frequencies are possible with a stiffer mounting or increased output voltage. The use of vibrating pager motors is attractive due to low cost and simplicity of implementation, but vibration amplitude and frequency cannot be controlled independently and neither parameter can be controlled precisely. This makes it difficult to prevent beats (low-frequency pulses) that can occur when multiple motors vibrate simultaneously at different frequencies. Anecdotally, the problem of beats has been minor with our array and is outweighed by the benefit of simultaneously activating multiple motors for anti-aliasing.

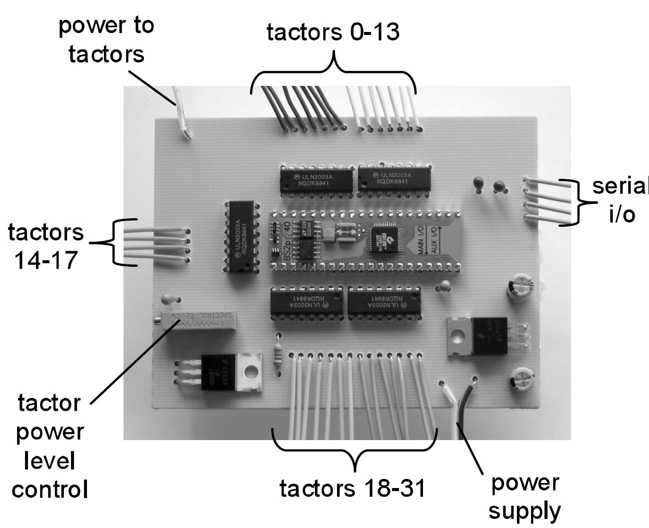

Fig. 2. First version of the controller

3 Observations and Future Work

Formal evaluation of the system has not been conducted but is planned for future work. We received useful feedback from several users during a recent demonstration at a major haptics symposium. Most users found the mapping from touchpad to palm to be natural and commented positively on the effect. Some users commented that the flat arrangement of motors was not ideal for the contour of a hand. Although the foam mounting allowed the array to deform slightly to users' hands, a dome-like arrangement would have improved consistency of contact between motors and the palm surface. Some small-handed users could not contact all 30 motors at once, and some users preferred to contact the array with their fingers or forearm. When presented with the ability to toggle options such as anti-aliasing and sensing of contact intensity by the touchpad, preferences varied. Comments about the anti-aliasing option suggested that the resulting sensations were smoother and that motor level appeared increased.

In addition to touchpad-driven communication, we have used the array to display direction vectors, shapes, and other information. Our initial reaction is that static "images" are difficult to interpret but that motions are understandable. More work is needed to determine what type of information can be displayed effectively.

We plan to improve feedback by calibrating motor levels to a perceptual scale and by optimizing the PWM patterns to provide the greatest number of useful levels without introducing perceivable pulses. Further development of anti-aliasing techniques for tactile arrays and evaluation of their perceptual effects are other interesting areas for future work.

Implementation details and additional information about the array can be found at *http://www.cacs.louisiana.edu/~cborst/tactilearray/*.

References

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