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The Design and Deployment of a Wearable Vibrotactile Feedback System

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Abstract

We present work on the development and deployment of a wearable system for displaying vibrotactile stimuli at multiple locations on a person. This system is targeted as a general-purpose controller, with the flexibility to support many types of output devices, such as pager motors, muffin fans, and solenoids. We describe the deployment of one configuration of our system for use in the military, and discuss design changes we made that resulted from this deployment. Our major design goals include physical robustness, light weight, low power, and wireless communication. Once these goals are attained, we will explore the size of the "vocabulary" of cues that can be unambiguously identified by the wearer.

1. Introduction

Wearable systems typically use the visual and auditory modalities to provide user feedback. We are developing a system for using the sense of touch as an alternative or supplementary channel for displaying information to users of wearable systems.

Over the past few years, we have been refining the hardware control system necessary for the support of a large number of vibrotactile output devices [7, 13]. In addition, we have constructed several systems for testing the use of vibration in various settings [15, 8, 9]. Haptic cues have successfully been used in virtual and real environments to draw the user's attention to an area of interest, to improve spatial awareness, and to deliver collision information when interacting with virtual objects.

We can augment the physical environment with vibrotactile feedback, providing aids through the haptic modality that support the task being performed. We can envision an approach where one person is guided through a physical environment by a second person who is monitoring the movements of the first using an existing tracking mechanism such as GPS. Instead of using the audio channel, however, directional vibrotactile cues are used as guiding aids. Similar approaches could be applied, for example, to guiding firefighters to search certain areas, such as bedrooms, for victims, or guiding blind individuals along a route through a city [1]. Another class of applications are those that require motion-following training, such as practicing Tai Chi forms [2], or a golf swing (*e.g.*, www.innsport.com). Finally, information transmission using the vibrotactile channel can help to off-load other modalities, or support non-verbal communication.

2. Background

There are a variety of ways to provide tactile cuing. For a number of reasons, including low cost, portability, relative ease of mounting on different parts of the body, and modest power requirements, we have been concentrating on the use of vibrotactile *tactors*. Tactors are devices that provide some form of tactile sensation.

A number of research groups have been exploring the use of multiple tactors within a wearable context [10, 11, 4, 3, 5, 12]. Though the torso has not been found to be the best body location for high-resolution vibrotactile feedback [14], those parts that are more perceptive to vibrotactile stimuli, such as the hands, are typically involved in other tasks, whereas the surface of the torso is relatively unused. Van Erp and his group have designed a system that was scheduled to fly aboard a Soyuz rocket to the International Space Station [3]. They have outlined several studies they plan to perform with astronauts to improve their ability to orient themselves, as well as to speed adaptation to the dynamically changing "artificial gravity vector," using localized vibration.

Amemiya, *et al.* [1] used tactors on the fingertips to communicate with deaf-blind individuals in a manner similar to the method used in real-life, where one person places their fingers on top of the deaf-blind person's fingers and taps out words. They also used a similar system to guide deaf-blind individuals along a route through a city. Their system uses a Linux-based wristwatch to control the vibrations, and short-range communication to support tetherless guidance.

Yano *et al.* [16] developed a suit-type vibrotactile display with 12 tactors attached to the forehead (1), the palms (2), elbows (2), knees (2), thighs (2), abdomen (1), and back (one on the left side and one on the right). They examined the effectiveness of using this vibrotactile display for tasks that required the user to walk around a virtual corridor visually presented in a CAVE-like display. They showed that presentation of tactile cues was effective for imparting collision stimuli to the user's body when colliding with walls.

In our own work, we have looked at determining the limits of perception of the human back in terms of vibration intensity and location discrimination [8], as a means of providing cues for virtual contact [6], as a way of conveying information by way of strokes for writing letters [15], and as a means for directing the user's gaze for predominantly visual search tasks [9]. Here we focus on more-applied aspects that must be addressed to deploy a robust, wearable system for information transmission.

3. System Design

The system we have deployed, called the TactaArmBand system, combines a TactaBox system with custom arm bands. Our major design goals include physical robustness, light weight, low power, wireless communication, and unambiguous cueing.

3.1. TactaBox Unit

To support the delivery of vibrotactile stimuli, we have designed the TactaBoard system [7]. The system can independently control up to 16 outputs with one-byte resolution (256 levels) using Pulse-Width Modulation (PWM) at a frequency of >300Hz. This frequency represents the period of the PWM signal. The actual frequency of the vibration is determined by the characteristics of the device connected to the output. The pager motors used in the current system have a frequency range between 80Hz and 160Hz. The frequency of each tactor is controlled by setting the duty cycle of each PWM signal.

We assembled the TactaBoard into a 15.2cm × 10.1cm × 5.1cm (6" × 4" × 2") box, with RJ-25 connectors for connecting to the tactors, a rechargeable battery, and wireless communication, to form a TactaBox (Figure 1).

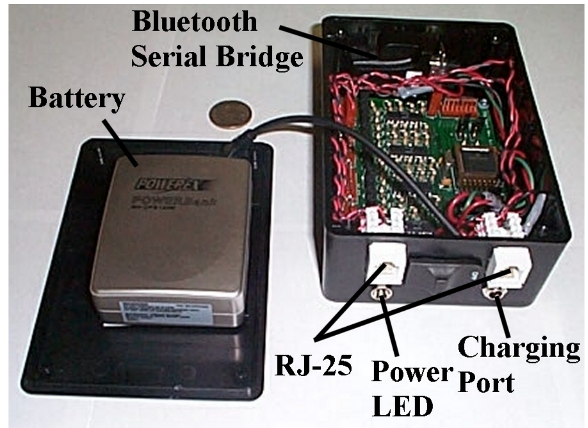

Figure 1: TactaBox with RJ-25 connectors used to connect to tactors. A U.S. quarter is shown for scale.

Power for this application is provided by a single rechargeable PowerBank NiMH battery (Maha Energy Corp., model MH-DPB180M, www.mahaenergy.com), with a capacity of 1800mAh, 6V at 500mA. The battery is fastened to the underside of the box lid with two-sided adhesive tape, and a cable runs from the battery to a switch accessible from outside the box. The switch determines whether the battery should be charged from an external AC adapter (OFF), or to power the TactaBoard (ON). The TactaBox communicates with the host using an ASCII serial protocol over paired Bluetooth serial port plugs (Free2Move AB, model F2M02, www.free2move.se), making it operating-system independent. The reported operating range of these Bluetooth devices is 100m, and in our deployment tests in an outdoor setting, we have achieved reliable communication over a 140m distance.

3.2. The Armbands

The vibrotactile stimuli are delivered using tactors placed inside of modified neoprene armbands (McDavid, Inc., model 204, www.mcdavidinc.com). Each armband (Figure 2) contains two tactors arranged vertically, one towards the elbow, and one towards the shoulder, on the triceps. The tactors, ruggedized in house, are Tokyo Parts Industrial Co., Ltd., Model No. FM37E, and have an operating voltage range of 2.5-3.8V at 40mA. They have a frequency of 142Hz at 3.0V, and have a vibration quantity of 0.85G.

We designed the shape of the tactor casing to be a disk with a cone on top that tapered to a near-point on the side that contacted the body (Figure 3). Several researchers have reported that maintaining good contact of the tactor with the body is a major problem in similar systems [10, 12], and this shape was chosen to mitigate this problem. The flat bottom helps to insure that pressure from the elastic armband is applied evenly across the tactor. The circular shape produces a region of influence of the vibration whose edges are equidistant from the center of vibration. Finally, the near-point cone helps better direct the vibration to a point on the person.

Figure 2: TactaArmBands attached to the TactaBox using coiled phone cord. Tactors are mounted on the underside of the armbands, covered by a thin piece of cloth.

The tactors are mounted using hook-and-loop fastener on the inside of the armbands, and covered with a thin piece of cloth for robustness. The hook-and-loop fastener allows the tactor location to be precisely adjusted. One coil telephone cable per arm band carries the power signal to the two tactors. The two coil cables connect to the TactaBox using RJ-25 connectors.

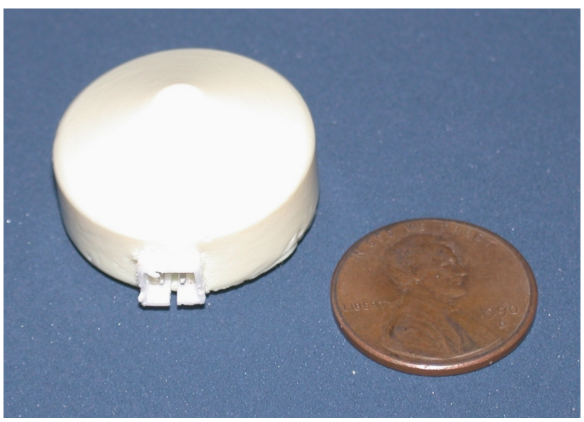

Figure 3: Ruggedized tactor, shown in relation to a U.S. penny.

4. Preliminary Deployment Test

We conducted a preliminary test of the system to assess the robustness, communications range, ease of donning/doffing, cable management, and location of TactaBox on the person. In addition, we wanted to determine whether the vibration is noticeable at different levels when performing physically demanding tasks. It should be noted that this was not a formal user study; we simply wanted to assess our implementation.

Three participants donned the TactaArmBand system and ran through different sections of an obstacle course. The TactaBox was worn inside a fanny pack, and the cables were run up the webbing of a harness to the armbands (Figure 4).

Figure 4: TactaArmBand system in a test deployment.

The obstacle course required the participants to crawl under barbed-wire, climb up and over a rope net, jump over barriers, run at high speeds, and crawl through pipes (Figure 5), among other tasks. A control program running on a laptop communicated with the TactaBox using the Bluetooth bridge, and the tactors were triggered in a random fashion at different locations on the course. Both the intensity level (full or half intensity) as well as the arm that was stimulated (right or left) were selected at random. When the vibration was felt, the participant called out "RIGHT" or "LEFT" to indicate both the time and location of the perceived vibration.

5. Conclusions and Future Work

In terms of robustness, upon inspection, the units showed no adverse affects after being worn multiple times through the course. The participants correctly identified which side (right or left) the vibration was on for each trial, including inside the metal crawl pipe. A communications test revealed a controllable range of 150-200m, well beyond the 100m specification of the Bluetooth devices. However, there was an occasional delay in participant response from the time the tactors were triggered, though the duration of the delay was not measured. While some of this is due to the Bluetooth technology, there was some indication that some of the delay was due to engagement in, and/or the physical demands of, the task, as the response during the rope-climb obstacle seemed to be the longest. The participants confirmed this finding. Donning and doffing of the system was deemed to be very straightforward, requiring only the hook-and-loop fastener of each armband to be adjusted, the cable-ties to be twisted, and the pouch holding the TactaBox to be fastened.

Figure 5: The pipe-crawl obstacle.

We are currently designing more-formal studies to measure the duration and source of the delay in the system, as well as the expressiveness of the language that can be transmitted. In addition, we have designed several other form-factors, including an eight-tactor belt and a sixteen-tactor upper-body garment, based on the lessons learned from this project.

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