Presenting a Biometrically-Driven Haptic Interaction Loop

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Abstract

Computer interfaces often make large demands on users' attention, both to request and gather input and to provide output (feedback). In this position paper, we propose a new style of interaction that minimizes these attentional requirements while still providing support for rich input and output. Physiological data is used to drive the execution of a program and direct its behavior, while mounted mobile tactile displays provide granular application feedback at an appropriate level of intrusiveness for the given context. We present evidence for the effectiveness of our interaction approach from the literature, and describe several existing and potential applications including smart portable audio players and spatiotemporal guidance systems.

1 Core Concept

1.1 The Biometrically-Driven Haptic Interaction Loop

Traditional computer interfaces make significant demands on our attention. Input and output channels typically conform to paradigms that rely on the visual channel (such as WIMP), which require the users' constant visual attention. We are often required to validate, override or alter the states of our computational devices; the means by which these devices demand our attention for these purposes are often highly intrusive, annoying, and potentially embarrassing, especially in mobile contexts [**1**].

We envision an interaction technique that seamlessly and quietly dictates the behavior of computational devices on the (at least partial) basis of biometric data gathered from the user, as well as other non-disruptive sources, and provides non-intrusive feedback through the haptic channel, which is underutilized and suited for background display. In this manner, attentional demands on the user would be significantly reduced, especially those in the visual domain; this leaves the user with the cognitive and visual freedom to perform other, perhaps more mission-critical, tasks in synchrony. Said another way, previously *explicit* user interaction with a system is transformed into an *implicit* operation.

1.2 Requirements

1.2.1 Appropriately Intrusive Feedback – The "Haptic Butler"

Maintaining high visibility of system status is a well-established principle in user interface design. As explicit human-computer interactions become implicit, the need for immediate and continuous but peripheral feedback from the system becomes more and more apparent. A key feature of our envisioned interaction technique is thus to provide this feedback in an appropriately intrusive manner.

Recognizing that a multitude of messages can be conveyed via human-to-human touch with nuances in intensity, pressure, frequency, and locus of contact portraying differences in meaning and urgency, we endeavor to emulate human attention-getting practices for the purposes of feedback. People generally possess the skills required to capture others' attention appropriately given the importance of their interruption and the current social context; meanwhile, knowledge of a co-worker's workload is helpful in minimizing intrusiveness [**2**]. We consider well-trained butlers to possess the most refined skills of this type, while also having good access to a master's state. We will use the metaphor of a "haptic butler" to describe our display approach. Changes to a system of little immediate consequence to the user would not, for example, result in a high-intensity vibration that mimicked rapid, relentless tapping by a human.

1.2.2 Biometrically Derived User Model

Knowing users' current affective and physiological states, their abilities, and their goals is essential to assisting them properly. From the parameters of non-autonomous body movements (such as gait frequency) to autonomous biological parameters such as heartrate, inferred states can help a smart system make better decisions for user assistance. As affective states manifest themselves differently among disparate users, a per-user model is required for best reliability in the system. Kulic & Croft utilized a hidden Markov model (HMM) primed on a per-user basis for real-time affective state estimation [**3**]. Models that are refined over time should facilitate increased accuracy and expedience in the identification of affective states.

2 Design Space

2.1 Tactile Display Parameters

Tactile displays are unidirectional physical interfaces that employ vibrations, tapping, stretching and compression of the skin, and indentation to convey messages (via “gestures”) to users [**4**]. Unlike force-feedback displays, tactile displays are not necessarily collocated with the input device and need not be grounded. These two characteristics make them suitable for portable and wearable devices. Several technologies have been employed in the building of tactile displays: mechanical vibration/tapping/squeezing, electromagnetic vibration (transducers), pneumatic vibration/squeezing, electrotactile, and temperature [**5**], [**6**], [**7**]. Producing mechanical vibration by rotating an off-centered weight attached to the shaft of a micromotor is widely used in consumer electronics but other mechanisms are gaining interest.

In addition to fingers and palms, which are the body parts most sensitive to tactile stimuli, many other areas can be targeted by tactile displays. This provides us with a wide range of possibilities for wearable displays: gloves, watches, wristbands, rings, shoes, vests, pendants, caps, earrings, and belts are all possible [**8**], [**9**].

For each of the main categories of tactile gestures, variation in signal frequency, amplitude, tempo, rhythm, and velocity can explode the design space and pose questions of distinguishability between similar signals, intrusiveness, and perceptual salience [**4**], [**6**], [**10**]. Swerdfeger *et al.* explored frequency, amplitude and rhythm variation in haptic (tactile) signals, and concluded that rhythmic differences in stimuli dominate other distinctions [**11**]. Further, groups of rapidly displayed pulses have particular perceptual salience and stimuli that vary only in frequency or amplitude are perceived as similar (but not identical).

We explored the delivery of two categories of tactile gestures (squeezing and tapping) in an iterative, experimental design cycle (details in [**7**]). A wrist watch prototype was developed, whose band was capable of expanding and contracting (and thus squeezing the user’s wrist) based on programmable waveforms (Figure 1). A tapping lever was also mounted on the device. Various sinusoidal, triangular and sawtooth-shaped waveforms (“profiles”) of varying velocity were displayed to the user in an evaluative study. The user was asked to select from a list of provided adjectives those that best described each profile. Among other results, we found that symmetric profiles were more likely to be described as reassuring and relaxing than asymmetric signals. Generally, subjects found the profiles to be expressive and differentiable. An array of tapping mechanisms was deployed in a second prototype (Figure 2) which allowed for expressive, rhythmic patterns (akin to finger drumming) to be displayed. A more robust prototype allowing for flexible placement and activation of tactors on clothing is also in development (Figure 3). An evaluative study of the latter prototypes is still required.

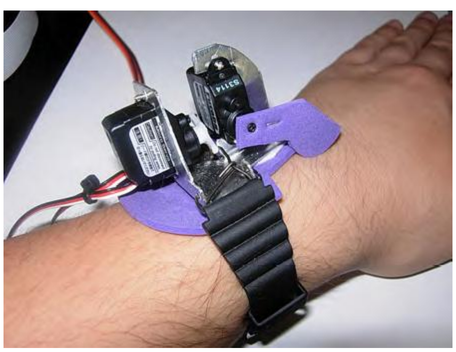

Figure 1: Wrist Watch Prototype

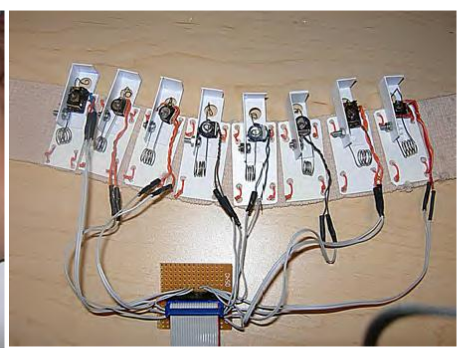

Figure 2: Tapping Array Prototype

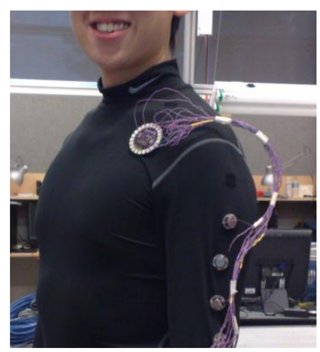

Figure 3: Clothing-Embedded Tactor Array Prototype

2.2 Command Channels

Commands, preferences, and goals of the user can be communicated to the system via conventional input devices such as keyboards, touch screens, mice, and joysticks. To avoid burdening the user with additional work, it is desirable to reduce the time and/or cognitive effort spent on input-related tasks. In this regard, we propose maximizing information collection from sources that do not require the active participation of the user.

Physiological signals, such as heart rate, perspiration rate, electrical skin resistance, and facial muscle contraction can be captured using a variety of sensors. These signals can be used in isolation or in tandem to inform internal user models and approximate affective states. System behavior can be explicitly altered as a consequence of state switches; detecting a shift from the “satisfied” state to “annoyed”, for example, could cause soothing music to begin playing.

2.3 Other Information Sources

Leveraging additional sources of data for altering system behavior can help reconcile contextual issues within a system developed with the proposed interaction paradigm. Explicitly defined user preferences are a simple example; depending on the desired deployment, third-party data such as GPS could also be used to inform system behavior in a richer manner. A database of user models or statistical usage data could help train the system faster than a single user could manage.

Intention prediction based on actions captured by motion sensors, positioning sensors, and bio-sensors is an effective, indirect technique to collect and exploit data with minimal active participation. Maintaining historical data to inform changes to individual user models is also effective in producing an iterative, long-term understanding of the user. Motion sensors can be used to collect data about users without requiring their explicit attention. They can be used to measure the speed/frequency of the whole body of the user or individual body parts (e.g. gait frequency). Position and orientation sensing are also very good ways to collect rich information about the user, particularly if he/she is trying to accomplish a task that requires movement in space.

3 Applications

3.1 Portable Audio

We propose that portable audio players could harness the power of the proposed interaction technique to autonomously select appropriate music for their users. With this approach, a jogger who becomes disinterested in a Podcast, for example, could expect music to begin playing on the basis of his dissatisfaction alone. An experiment to determine the feasibility of modeling music-related affective signals is currently underway. The goal is to determine general trends in physiological data when users are enjoying (or not enjoying) their music in task-based contexts.

3.2 Spatiotemporal Guidance

Guidance is a general term used to describe systems that help users accomplish tasks by providing information about a task, suggesting actions, and/or sharing in system control. Vision and audition were the traditional primary communication channels of early guidance systems [**12**], [**13**]. Haptic (tactile and proprioceptive) guidance is becoming more and more popular because visual and auditory channels are often required for the primary task; guidance systems by design should not become a source of distraction for users. A wide range of haptic guidance methodologies, from telepresence and object manipulation [**14**], [**15**] to shared control of inland vehicles [**16**], [**17**], [**18**] and wearable navigational guidance [**8**], [**9**], [**19**], [**20**] is dedicated to guiding users in space. However, temporal parameters are also very important to task completion [**21**].

Considering the design space for haptic displays, especially the inherent temporal nature of touch, it seems natural to exploit the haptic channel in the production of spatiotemporal guidance systems. Wearable guidance systems for athletes are specific examples of such systems. They can communicate a reference/desired gait frequency to a runner, for example, so that he/she can use it for a gradual increase of running speed. Similar devices could be imagined for rowers or cyclists. Spatiotemporal haptic guidance can also be used for guiding training and performances of music and dance. It can play the role of a “private” conductor that can help synchronize artists and cue them for special parts of the performance.

3.3 Physiological Guidance

Certain classes of users are interested in receiving guidance with respect to their physiological states themselves. Athletes who aim to reach peak performance in their field, practitioners of alternative medicine and spirituality, and those who which to maximize work productivity by entering “flow” states are examples of such users. In a tight interaction loop where tactile feedback mirrors or encourages changes to users’ physiological states, guidance toward a target state can be naturally facilitated.

4 Conclusion and Future Work

This position paper presents a case for an interaction technique that involves minimal user interference, in both its input and output channels. The interaction technique involves a largely physiological-based input space, and uses the underutilized haptic channel to provide appropriately intrusive feedback. Several existing and potential applications of such an interaction style were introduced, many of which are under current experimental investigation.

Future work will center on validating user model creation for the contexts we wish to address (mainly portable audio and spatiotemporal guidance) and developing an integrated system involving the proposed interaction technique. In the haptic space, work will focus on developing and evaluating languages of communication for the particular contexts, comparing those that mirror the state of the system or user with those that use more abstract messaging paradigms (e.g., haptic icons [**11**]). As a significant goal of our proposed interaction technique is to minimize the cognitive load on the user, the degree to which the signals can be naturally interpreted is of particular interest.

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