

Information Transmission with a Multi-Finger Tactual Display

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ABSTRACT

This work was motivated by our interest in using the sense of touch as an alternative communication channel for sensory substitution. Previous research has demonstrated that some deaf-and-blind individuals can receive conversational English at almost normal rates using the Tadoma method, in which the user places a hand on the face and neck of a talker and monitors the mechanical actions associated with speech production. To this day, however, no one has achieved a similar performance level with electromechanical devices developed for tactual speech communication. These devices typically do not engage the hand and use homogeneous vibrotactile arrays that lack distinctive perceptual qualities. In contrast, Tadoma makes use of the hand and a rich display, the talking face, that involves kinesthetic stimulation (low-frequency large-amplitude motions) as well as vibrotactile stimulation (high-frequency small-amplitude vibrations). A major goal of this research is to explore how information transmission can be improved by simultaneously stimulating both the kinesthetic and tactile components of the tactual system.

A multi-finger positional display, the TACTUATOR™, was developed. It consists of three independent single-contact-point actuators interfaced with the thumb, the index finger, and the middle finger. Each actuator utilizes a disk-drive head-positioning motor augmented with angular position feedback from a precision rotary variable differential transformer (RVDT). A floating-point DSP system provides real-time positional control using a digital PID controller. It is capable of delivering arbitrary waveforms within an amplitude range from absolute detection threshold to about 50 dB sensation level, and a frequency range from near DC to above 300 Hz (e.g., 25 mm

slow motion with superimposed high-frequency vibration). Actuator frequency and step responses are well modeled as a second-order linear system. Distortion is low. System noise and inter-channel crosstalk are also small. Absolute thresholds measured with the stimulator are in general agreement with results from the literature. Overall, the TACTUATOR accurately follows its drive waveforms and is well suited for a variety of multi-finger tactual perceptual studies.

The information transmission capabilities with the TACTUATOR were assessed through a series of absolute identification experiments with human observers. In exploring the stimulus attributes that are most effective for producing a large set of clearly distinguishable stimuli with the TACTUATOR, it was found that subjects could naturally categorize motions over the entire frequency range into three perceptually distinctive groups: slow motion (up to about 6 Hz), a rough or fluttering sensation (about 10 to 70 Hz), and smooth vibration (above about 150 Hz). Multi-component stimuli were formed by simultaneously stimulating multiple fingers with waveforms containing sinusoids (varying in both frequency and amplitude) from the three frequency regions. Stimulation was applied to either one of three digits (thumb, index, or middle) or to all three digits simultaneously. For a stimulus duration of 500 *msec*, information transfer (IT) was 6.5 *bits* (corresponding to perfect identification of 90 stimuli); at 250 *msec*, IT was 6.4 *bits*; and at 125 *msec*, IT was 5.6 *bits*. Estimates of potential IT rates were obtained by sequencing three random stimuli and (a) having the subject identify only the middle stimulus and (b) extrapolating this IT to that for continuous streams. Stimulus durations of 125 to 500 *msec* and presentation rates of 1 to 7 *items/sec* were tested. Estimated IT rate was about 12 *bits/sec*, and optimal stimulus presentation rates were between 2–3 *items/sec* independent of stimulus duration. This IT rate is roughly the same as that achieved by Tadoma users in tactual speech communication.

In addition to the above work, several related issues were identified for further investigation: selection of stimulus uncertainty for maximizing information transfer, definition of stimulus-set dimensionality, and relationship between the capability to receive motional input sequences and one's ability to deliver the same motor outputs.

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