PossessedHand: Controlling Hand Movements with Computer Output

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A prototype HCI system demonstrates the effectiveness of using computer-generated electrical stimulation to control muscles.

In a traditional human-computer interaction (HCI) system, a user controls the system through various input devices, and the system presents output in a way that human senses such as vision, hearing, or touch can perceive.

The PossessedHand HCI system uses computer output in the form of electrical stimulations from multiple, noninvasive electrodes attached to the forearm to control the subject's hand movements. We envision this technology as having application in systems for learning or guiding execution of various physical skills, such as playing a musical instrument, as well as in rehabilitation systems. The system's feedback method could be applied to interactive systems in general.

SYSTEM OVERVIEW

As Figure 1 shows, the PossessedHand prototype consists of two belts, each with 14 embedded electrodes, that attach to the subject's forearm; a switching board; a battery; a condenser for generating the electrical pulses; and an Arduino Mega microcontroller connected to a PC via a USB cable.

A GUI on the PC provides the means to vary the stimulation level and thereby control the forearm and wrist muscles connected to the subject's hand. With 12 available stimulation levels and 14 electrical paths, 168 stimulation patterns are possible.

The electrical pulse frequency is set at 40 Hz, the pulse width is 0.2 microseconds, and the voltage ranges from 17 to 42 V. Proper location of the electrodes is critical—positioning the forearm pads can take a lot of time and requires precise anatomical knowledge. As forearm size differs from person to person, the belts must be custom-fit to each user.

An automatic calibration system identifies the stimulation patterns that control the subject's hand and selects the optimal stimulation levels for each joint movement. This calibration is a control loop using the touchscreen as input and human muscle activity as output.

EXPERIMENTAL EVALUATION

To evaluate PossessedHand, we measured finger-joint movement induced by the system on one hand of eight subjects. We conducted three trials on each of the hand's five fingers, resulting in 120 total movements per subject. The duration of each trial was three seconds.

As Figure 2 shows, the system moved all 14 finger joints, as well as the wrist, of each subject with varying degrees of control. The subjects could feel each movement and, even blindfolded, could correctly guess which joints were being controlled.

We used a table-mounted spring scale to measure the maximum force, in grams, exerted by each of the subjects' fingers during each trial. The stimulation was set at the maximum safety level, and the voltage was limited to 42 V. To prevent the subjects from accidentally moving their hands on their own, we instructed them to place their hands flat on a desk.

Figure 3 shows the results of this experiment. The average force recorded for all five fingers was 88.75 g. In general, PossessedHand can't yet induce movement forces sufficient to grasp objects. However, more accurately calibrating the relationship between the electrical stimulation level and amount of bend in the joint could narrow this gap.

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Figure 1. PossessedHand system prototype.

APPLICATION: LEARNING TO PLAY THE KOTO

One application of PossessedHand is helping a beginner learn to play a musical instrument. We developed one example application for the koto, a traditional Japanese stringed instrument that requires complex finger movements to achieve subtle tonal differences.

Kotos are about 180 cm wide and made of paulownia wood. They have 13 strings stretched across 13 moveable bridges along the width of the instrument. A koto player plucks the strings with picks worn on the thumb, index finger, and middle finger of one hand.

A koto score includes string numbers, time signatures, and finger numbers, and it's difficult to read all three simultaneously. As Figure 4 shows, PossessedHand "tells" a beginning player which fingers to move and when, enabling the player to focus on the string numbers.

After transcribing several koto scores to PossessedHand stimuli, we had four novice players alternate between normal playing and playing with the aid of our system. Over the course of 36 trials, all four players

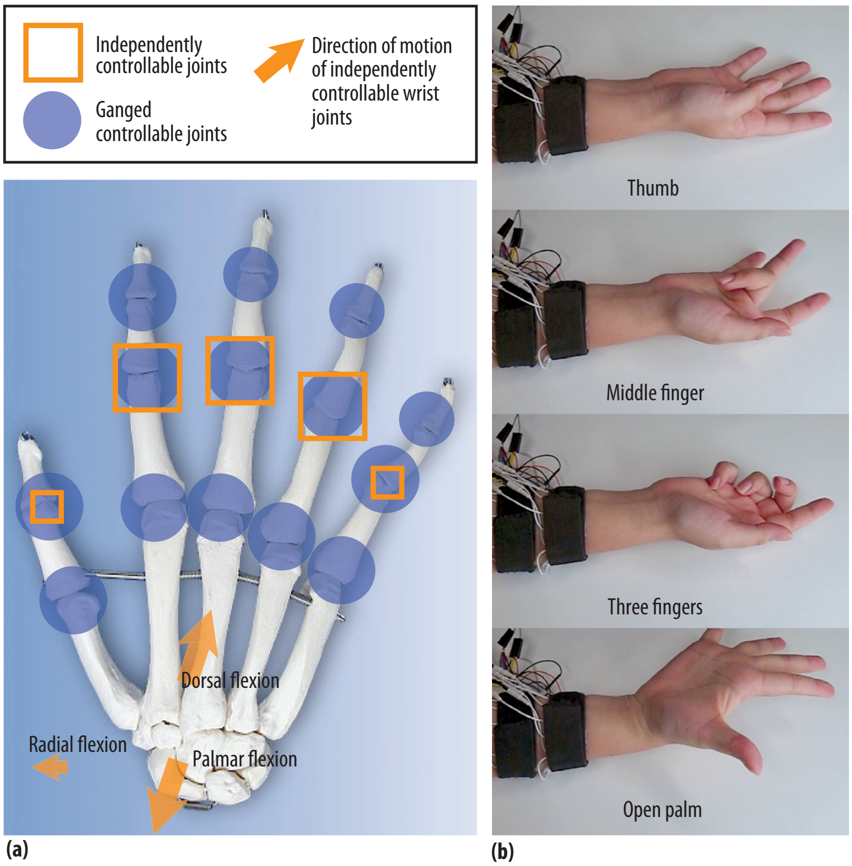

Figure 2. Controlling finger and wrist joints with PossessedHand. (a) The size of the colored overlay indicates the system's relative ability to manipulate each joint. Ganged controllable joints can only be moved in conjunction with other joints. (b) Examples of induced hand movements.

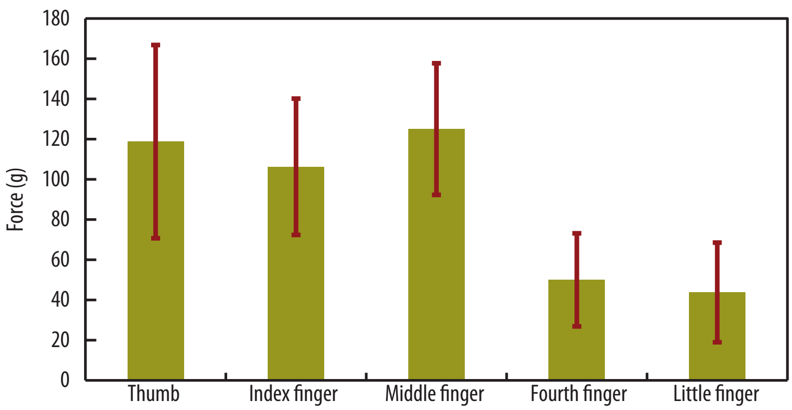

Figure 3. Average force exerted by each finger when subjected to electrical stimulation by PossessedHand. The red lines within the bars denote the range of standard error values.

Figure 4. Using electrical stimulation, PossessedHand "tells" a beginning koto player which fingers to move and when, enabling the player to focus on the score's string numbers.

demonstrated a better sense of rhythm and made fewer errors using PossessedHand.

FUTURE RESEARCH

Our immediate goal for future research is to refine the use of PossessedHand in teaching beginners to play music, perhaps expanding to other instruments beyond the koto. A major part of learning to play an instrument is mastering the required finger movements and timing, which can be fatiguing. We believe that electrical stimulation of the muscles involved in these movements can accelerate the learning process and enable novices to become skillful players more quickly.

We envision using PossesedHand to guide other difficult tasks, such as flying a helicopter or drawing, or to aid in physical rehabilitation. In addition, the system currently controls movements in only one hand, and including both hands could unlock many other possibilities. We're also considering applying controlled electrical stimulations to different areas of the body, such as the shoulder.

Our PossessedHand experiments raised questions about subjects' control of their body. Few had previously experienced electrical stimulation that influenced their muscular movements, and some were frightened by the technology. Subjects imagined malicious hackers getting access to such a system and forcing them to do something against their will—even commit a crime.

Our prototype system's maximum electrical stimulation level is too low to overcome subjects' resistance. However, to ease safety concerns, we're testing the system on a broader population of users and are considering safeguards against hackers.

PossessedHand demonstrates the effectiveness of using computer-generated electrical stimulation to control muscles, which has numerous potential applications in a wide variety of fields. Although some subjects in our experiments were initially put off by the system's novel feeling, we believe that, with improvements over time, the technology's convenience will overcome most user reservations.

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