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ABSTRACT

The human body is full of electrical signals. We propose to use the electric signals produced by the human body to input text without the use of a physical keyboard. We allow users to tap their fingers in the air as if typing on an imaginary keyboard. To detect the tapping, we created a wearable armband that uses electromyography (EMG) sensors to track individual finger muscle activation. Each finger is mapped to several characters, and based on the finger-sequence the user taps, a list of possible typed words is presented. Augmented reality and virtual reality headsets are becoming more prevalent (Oculus Rift, Microsoft Hololens, Google Cardboard, Magic Leap), and yet none of the existing typing techniques allow the user to easily input text while using these devices away from a desk. Giving users the ability to input text without using a physical keyboard opens up the possibility of using AR or VR in any location. We discuss the challenges in making our initial prototype more practical, robust, and reliable as part of our on-going research.

1. INTRODUCTION

The electrical signals within the human body are an underutilized tool for interacting with computers. Given the availability of low-cost electromyography (EMG) sensors like the MyoWare Muscle Sensor (about $35 for each sensor) and microcontrollers such as the Arduino, we now have the ability to use human produced electrical signals as input. Users can flex their muscles and a computer will respond.

In this paper, we present the design, implementation, and challenges of our Air Keyboard system, a motor-neuron to computer interface that uses the MyoWare Muscle Sensor EMG, an Arduino, and a simple predictive text algorithm. The user wears the EMG sensors on her forearm, and then moves her fingers in mid-air as if she were typing on an imaginary keyboard. Based on the order in which the user taps her fingers, our predictive text model presents a list of words she could have typed.

We demonstrate that this approach is currently not feasible or practical for mid-air typing, but that in the future, a slightly different approach could be more effective. While our initial attempt at an air-typing interface proved unsuccessful, responses from users indicate that people are interested in the idea of typing without a keyboard. A number of challenges remain in developing a practical air keyboard. Further research addressing the challenges of working with EMG sensors will likely be conducted in the future.

2. MID-AIR TYPING APPLICATIONS

As the presence of virtual and augmented reality increases, the need for novel human-computer interactions will also increase. Rather than sitting at a desk with a keyboard, or holding a phone to text, users will eventually want the ability to input text while moving around in virtual and augmented worlds. We imagine many applications for our new air typing method. For example, consider a virtual reality exploration or military environment. Users could be exploring a new world and taking notes on what they observe without needing to hold anything in their hands.

3. BACKGROUND ON EMG

For our air keyboard implementation, we decided the best approach was to use EMG sensors to detect electrical activity in the muscles located in the users' forearms. Humans have motor neurons, which transmit electrical signals that cause muscles to contract. An EMG uses electrodes to detect these signals. An electrode is an electrical conductor that makes contact with a nonmetallic circuit – in this case, human skin. An EMG has three electrodes - an anode, a cathode, and a ground. The anode is the electrode where electrons leave, and the cathode is the electrode where electrons enter. We decided to use EMG sensors because they do not impede finger/typing movement, and EMG electrodes can be sewn into fabric, which could eventually be made into a comfortable sleeve.

4. IMPLEMENTATION

In this section, we discuss the implementation details of the finger movement detection and the predictive text algorithm.

4.1 FINGER MOVEMENT DETECTION

To detect muscle activation, we decided to use MyoWare Muscle Sensors. The MyoWare Muscle Sensors output an analog signal between 0 and +5V. When the user flexes, the voltage increases. If the user flexes harder, then the voltage will increase even further. The MyoWare Muscle Sensors were selected because they preprocess the electrical signal. Conveniently, the primary output is not a raw EMG signal, but an amplified, rectified, and integrated signal, which is compatible with an Arduino microcontroller

For our finger-movement detection, we decided to use a threshold-based approach. This is one of the areas where our project could be improved significantly. We attached one EMG sensor to the forearm for each finger the user uses for typing. When the user moves a finger, the corresponding EMG sensor will output a signal. If the signal is over a certain threshold, then it will register as a tap. This has several problems. First, it requires that the user wear four or five (depending on if the thumb is used) sensors on each arm. This proved to be clunky and made it difficult for users to move comfortably. Second, it leads to suboptimal accuracy. Because the finger muscles are so close together and the sensors are close together, the movement of one finger is registered on multiple sensors. The particular sensor that is optimally located for the moving finger generally has the highest output, but the other sensors can have a non-trivial output as well, sometimes exceeding the threshold. This means that if the user taps her middle finger, our Air Keyboard might register both a middle finger tap and an index finger tap.

In the future, to fix these issues, rather than use a threshold-based approach, we would use a machine learning approach. We could reduce the number of required sensors to two or three, and then based on the combination of inputs that the sensors receive, we could determine which finger was pressed. This machine learning approach is much more sophisticated, and, given more time, we would have explored it further.

4.2 PREDICTIVE TEXT

We based our predictive text approach on the T9 texting algorithm and the "1Line Keyboard" approach [1]. That is, we mapped characters to each finger, and then based on the order in which the user taps her fingers, we presented a list of possibly typed words. In order to determine how we should map the characters, we had users type pangrams, and we monitored which fingers were used to type which characters. For the possibly typed word recommendations we used a 10,000-word corpus of most frequently used English words. This approach required that users be familiar with touch typing and using all of their fingers to type. We observed that there tended to be little overlap in which fingers typed which characters. Some characters are mapped to multiple fingers, but in general, each finger consistently taps the same characters. Each finger was mapped to three to seven characters.

This approach presents several challenges. One, it requires that the user know how to touch type and use all their fingers for typing. If they type by "hunting and pecking" with their index fingers, then each index finger will be mapped to half of the keyboard, and the predictive text algorithm will not have enough information to present useful possibly typed word recommendations. Two, it requires that the system be calibrated for each user. A more effective system might start with default finger mappings, and then as the user types more, the mappings would adapt to learn the user's typing preferences. Third, the quality of our predictive text algorithm's word recommendations depends on the quality of the corpus. We used a static corpus ordered based on frequency of occurrence in English. A more sophisticated system would adapt to learn which words a particular user types more often and would allow users to type words that were not originally present in the corpus.

5. PRELIMINARY USER STUDY

For our preliminary user study, we split our tests into two sections. First, we tested whether or not the user was comfortable using the EMG sensors and typing in mid-air. This was not connected to the predictive text algorithm; this was simply a test of whether the users were comfortable with the motions and device. Second, we tested whether or not the user was comfortable using the predictive text algorithm when typing on an actual keyboard. The user would type using only one line of the keyboard. Each finger would only press one designated key.

5.1 EMG TESTING

For the EMG sensor section of the study, we attached four MyoWare Muscle Sensors to the user's right forearm to detect each finger (minus the thumb). We asked each user first to tap each finger slowly in order, index finger to pinky finger, and noted if our Arduino program accurately identified each finger movement. Next, we asked the user to pretend to type the pangram "a quick brown fox jumps over the lazy dog" in mid-air five times. We visually noted which fingers the user used.

The results were mixed. We tested using three separate users, each right-handed, self-proclaimed proficient typists, and 20 to 22 years of age. None of the users had a problem typing in mid-air because each user was a proficient touch typist. The problem was, however, that when the users typed at full speed, the sensors rarely registered the correct finger tap order. For a majority of the imaginary "key presses," more than one sensor registered that its corresponding finger was pressed. Only one sensor should exceed the "tap threshold" per character. Even if the users slowed down their typing, the sensors still tended to be inaccurate. The users also commented on their discomfort from wearing four sensors on their arm. This led us to the conclusion that the idea of typing in mid-air has been validated; we just need a more appropriate and accurate way of determining the order in which fingers were tapped. EMG sensors attached to the forearm may not be the correct approach moving forward.

5.2 PREDICTIVE TEXT TESTING

For the predictive text section of the study, we had the users place their left hand fingers on the keys "a, s, d, f" and their right hand fingers on "j, k, l, ;" and type the pangram from the previous part of the study. For typing, they had to imagine which finger they would have used if they had the full keyboard, and then press the key directly under that finger. Their fingers did not move from the resting position, they only pressed the key they were directly above. They could only interact with this one line of the keyboard.

These results were also mixed. Users were able to learn how to use the system, but they struggled to keep their fingers on a single row of the keyboard. This caused them to slow down their typing because they could not simply type freely. The typing speed in terms of words-per-minute of the one-line typing was about one-fourth the typing speed of free typing.

Based on the comments and observations from users, we realize that this Air Keyboard system will only be viable if the users can type freely, without constraint, and if the users' finger taps are accurately detected. Anything short of that and the users will be uncomfortable and will reject using the system.

6. RELATED WORK

For tracking individual finger/hand/arm movement, researchers have used EMG sensors attached to the user's forearm; however, these devices have never been optimized for "air keyboard" typing [2,3]. They have been used to detect more general hand gestures. For tracking mid-air typing, specifically, researchers have used devices with cameras, which track a user's typing motion and finger location [4,5]. Some researchers have also attempted to track finger and typing movement by using gyroscopes and accelerometers [6, 7]. In addition to previous "air-typing" solutions, some researchers, such as the creators of "1Line Keyboard," have tried to improve typing on mobile devices by creating more efficient predictive text models [1]. Our approach combines the existing EMG technology with the existing predictive text paradigms to create a new, faster air-typing experience.

7. CONCLUSION

We have presented our evaluation of the initial Air Keyboard prototype, which uses EMG sensors and a predictive text algorithm to detect finger movements and to present a list of possibly type words. Although the project did not result in a working product, it did reveal the power (and drawbacks) of using electrical signals for communication and human-computer interaction. This Air Keyboard research opens up new opportunities for considering how to input text in virtual and augmented reality environments. As more accurate, precise, and cost effective methods for detecting muscle activity are developed, our Air Keyboard will become more feasible.

8. FURTHUR STUDY - ELECTROMAGNETIC RADIATION

Partway through our work on the mid-air typing project, we noticed a very interesting phenomenon with the EMG sensors. When we put a sensor facedown on a tabletop, then waved our hand underneath the table, the sensor would output a signal – indicating a potential difference between the anode and cathode electrodes. This observation led us to investigate medium-range electrical signal communication.

Electromagnetic radiation is everywhere. It occurs whenever an electron is accelerated or decelerated. Visible light and WiFi are both examples of EM radiation, but each has a different frequency range. We realized one example of a household object that emits EM radiation is the Plasma Ball, which emits EM radiation in about the 10 kHz range.

We had plans to use the Plasma Ball to transmit information within a room. We would modulate the Plasma Ball's EM radiation by rapidly turning the ball on and off. This would be an example of amplitude modulation (as opposed to frequency modulation). Before we found a method of rapidly modulating the Plasma Ball's EM radiation, however, we noticed another interesting phenomenon. If we touched the Plasma Ball, then our bodies could act as a "bridge" and extend the range of the signal. This made us explore the idea of using our bodies as a medium for sending messages.

We found an existing project called EM-Sense that was looking into this as well [8]. The EM-Sense paper described how a user could touch everyday objects to transfer the object's EM signal through the user's body to a specially designed smart watch receiver. The paper found that electronic and metallic objects each had unique EM signatures that could be determined simply from a human touch and a smart watch.

Our exploration ended soon after discovering EM-Sense, but given more time we would have explored this question: What properties of an object can be inferred if you know the object's EM signature? If a blind user touches an unknown object, could the EM signature reveal that the material was made of aluminum? Could it reveal that the object was very large or very small? These are questions that could be explored in the future.

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