Optimal Selection of Electrodes for Muscle Electrical Stimulation Using Twitching Motion Measurement

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ABSTRACT
Muscle electrical stimulation envisions a wide range of human augmentation application. However, the applications commonly have issue of optimal electrodes placement. In this paper, we propose a method to select the optimal electrodes placement for finger flexion using twitching motion measurement. We delivered electrical stimulation producing twitching motion and measured the acceleration. By summing and averaging the acceleration waveforms and taking the difference between the maximum and minimum value, we measured the contribution of the electrical stimulation and used it to select the optimal electrodes pair for the movement. Preliminary experiment with four electrodes showed feasibility of our method.

Categories and Subject Descriptors
H.5.2 **[Information Interfaces and Presentation]**: User Interfaces – *Haptic I/O, Prototyping, Theory and methods*.

General Terms
Algorithms, Measurement, Human Factors.

Keywords
Electrical stimulation, FES, Twitching motion, Electrode, Selectivity.

1. INTRODUCTION
Electrical stimulation of muscles and nerves envision a wide range of human augmentation application. While it has been used for muscle training and restoring function in people with disabilities (FES: Functional Electrical Stimulation), it is also proposed to be used for a kinesthetic sense presentation in virtual reality system, or to present information using the body movement itself [1].

On the other hand, the applications of muscle electrical stimulation commonly have issue of optimal electrodes placement. Our body is constructed by many muscles that are closely overlapped, thus it is difficult to independently control each muscle. Furthermore, relative position between the skin and the muscles change dynamically with movement; thereby, the calibration of the optimal electrode placement should be done online, especially when using surface electrodes.

To solve this problem, we propose a method to select the optimal electrodes placement for finger flexion using twitching motion measurement. While small twitching motion can be easily generated by electrical stimulation, we usually do not twitch intentionally, making it possible to distinguish between the active motion of the user and the passive motion by the electrical stimulation. By measuring the twitch by the electrical stimulation repeatedly with different electrodes pair, we could find the optimal pair. This paper shows the system and preliminary results.

2. RELATED WORK
Several studies have focused on solving the problem of optimal electrodes placement. Tamaki et al. [1] have developed 14 electrodes system for finger movement, as well as a GUI that the user records the movements of the fingers by each electrodes pair. Popovic-Bijelic et al. [2] presented a multiple-contact surface electrode with 24 conductive regions. The regions were controlled individually, thus it was possible to change the electrode shape as well as the position. However, in both cases, manual operation is required, which hinders online adjustment. The user needs to calibrate the optimal electrode placement each time the body position changes, which makes it difficult to use in daily life.

On the other hand, Malesevic et al. [3] proposed to use muscle twitch responses to optimize multiple-contact electrode selection. The twitch response signals were distinguished between different waveform classes using Artificial Neural Network (ANN). However, the ANN needs to be adapted to each user to achieve accurate classification; therefore, it is difficult to correspond to the change of situation.

3. METHOD
3.1 Hardware
The system consists of an electrical stimulator, a motion capture device and four electrodes (Figure 1). The electrical stimulator is able to control four electrodes simultaneously by a microcontroller (mbed NCP LPC 1768, NXP Semiconductors.) that is connected to the PC via a USB port. The amplitude of the stimulation can be adjusted by moving the slider. The maximum amplitude is 20mA. We used a digital 3-axis acceleration sensor (BMA180, Bosch Sensortec.) as the motion capture device. The sensor is connected to the microcontroller via I2C port. The sampling rate is 1kHz. We used four disposable electrodes (Vitrode F-150S, 18x36mm, Nihon Kohden.) and placed them on the palmar sides of the forearm (see Figure 1). We chose two electrodes as an electrodes pair, one from distal side and one from

proximal side (i.e., anode and cathode.); thus creating four electrodes pairs (i.e., pair AB, AC, BD and CD). We excluded pair BC and AD because the forearm muscles have oblong structure; therefore a much wide area can be stimulated by using the vertical electrodes.

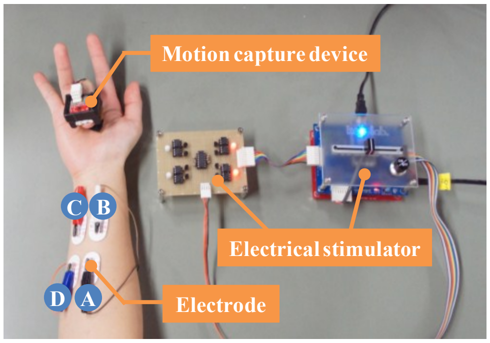

Figure 1. An electrical stimulator, a motion capture device and electrodes.

3.2 Algorithm

For each combination of two electrodes, we delivered electrical stimulation producing twitching motion and measured the acceleration data from the motion capture device. The output becomes an oscillatory waveform that corresponds to the stimulation frequency. By summing and averaging the waveforms and taking the difference between the maximum and minimum value, the contribution of the electrical stimulation can be measured (Figure 2). The electrodes pair that has the highest contribution is the optimal electrodes pair for the movement.

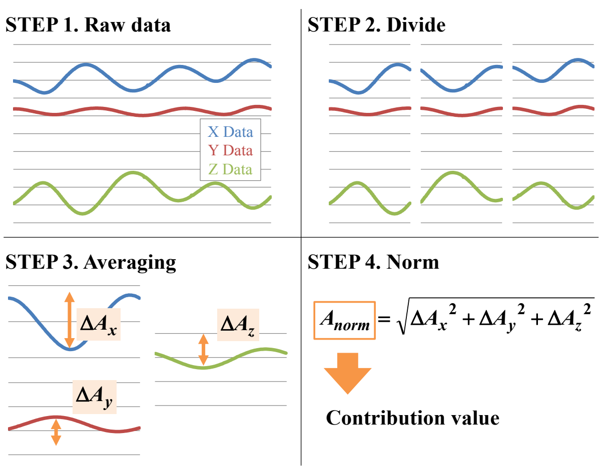

Figure 2. Algorithm to measure the contribution value.

4. EXPERIMENT

In this experiment we targeted the right middle finger and verified the possibility of obtaining optimal electrodes pair according to various position of the forearm by monitoring the twitching motion of the middle finger.

4.1 Procedure

The experiment included one participant (mid-twenties, woman) with no known neurological disease history. Four electrodes were placed on the palmar sides of the forearm were the muscle moved significantly while bending the middle finger. The participant was seated in a chair with the arm hanging relaxed next to the body. She was asked to rotate the forearm to four different angles and maintain the position. The four required positions of the forearm were pronation of 0, 90, 180 degrees and supination of 90 degrees. The neutral (zero-degree) position was the position where the palmar was facing the body.

In each position, stimulation via each electrodes pair was presented and the twitching motion was recorded simultaneously. All four electrodes pairs were activated sequentially. This procedure was repeated five times for each position.

For the stimulation we used bipolar pulse wave with pulse duration of 0.2ms and frequency of 100Hz. The amplitude was set to 10mA. To produce a twitching motion, we set the pulse train duration to 50ms and the pause between trains to 50ms. Thereby the division window size was 100ms (see Figure 2-STEP 2.). 10 pulse trains (1s) were delivered via each electrodes pair sequentially.

4.2 Results

Table 1 shows the contribution value based on the acceleration of the twitching motion for each electrodes pair and forearm position. The yellow indicates the highest contribution value for each position. The values differed significantly for each position and electrodes pair, implying the possibility of selecting the optimal electrodes pair based on the acceleration of the twitching motion.

Table 1. Acceleration based contribution value for each electrodes pair and forearm position. (mean (+/- SD) [m/s^2])

Electrodes pair	Forearm position [degree]			
	-90	0	90	180
AB	2.94 (0.80)	4.29 (0.27)	0.83 (0.53)	0.67 (0.18)
AC	1.41 (0.49)	2.28 (0.61)	3.93 (0.60)	3.99 (0.22)
BD	0.37 (0.20)	1.91 (0.20)	6.02 (0.23)	5.72 (1.02)
CD	0.32 (0.06)	0.53 (0.60)	6.49 (0.18)	6.21 (0.50)

5. CONCLUSION

In this paper we proposed a method to select the optimal electrodes placement for finger flexion using twitching motion measurement. Preliminary experiment with four electrodes showed feasibility of the method. Our future works include faster identification of the optimal pairs and further addition of more electrodes to control each finger independently.

6. REFERENCES

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