CLASSIFICATION AND SORTING OF PREFIXED CHANNELS FOR FUNCTIONAL ELECTROESTIMULATION AND VERIFICATION PROTOCOL ENEBI 2018

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Abstract. *A current challenge of functional electrostimulation (FES) using surface electrodes is finding the best position of the electrodes. This work proposes the use of an adjustable structure consisting of several surface electrodes which cover the entire area of interest, providing an easy and fast positioning of the electrodes. A new protocol for channel selection is also described in order to increase maximum repetitions for knee extension exercises after a short setup period. In order to validate the proposed setup, a comparison is made between a 3 channel selection according to this protocol and a single channel placed according to the standard trial and error placement method for knee extension. As a result, the proposed approach performed a substantially greater amount of repetitions of the exercise. Its expected that the proposed method may be a tool to improve exercises performance on FES rehabilitation.*

Keywords: *FES, Channel Selection, Neurorehabilitation*

1. INTRODUCTION

Known among therapists, FES (Functional Electrical Stimulation) has shown itself a very important ally to rehabilitation for patients with SCI (Spinal Cord Injury) or neurological dysfunction in a broad range of severities (LYNCH et al. 2000) and (POPOVIC et al. 2008). Even though optimization of stimulation parameters has been approached (KRUEGER-BECK et al. 2010), there is still no proposition of an optimal positioning display of electrodes. Improvement of performance — as delay to fatigue (BINDER-MACLEOD et al.) —, safety, comfort and long term results are questions still open. This paper, however, has the purpose of general improvement, not in the electro physiological aspects of the technique itself, but in its application in a well-structured manner, that aims to solve questions that concern positioning and placement of electrodes, as the automation of the selection and classification of stimulation channels involved in a given practice.

2. MATERIALS

The proposed system consists in an 8-channels electrostimulator, a inertial movement unit (IMU) sensor and an elastic fixing mechanism. Electrodes sized according to protocol are positioned across the thigh of the subject, and knee angle variation is measured as each pair of electrodes is stimulated, relating movement response to channel and electrical current parameters, generating data to be used by protocols which promote an improvement in performance, when compared to the standard trial and error method.

2.1 Stimulator

Hasomed's RehaStim Stimulator is a portable electrical stimulation device that generates pulses simultaneously in up to eight channels to activate muscles fibers through surface electrodes. It features USB connection and contains a software module for research applications. The generated signal is a biphasic pulse sequence, which is known to provide a good compromise with respect to performance and potential tissue damage. The assortment of the fixed parameters was made according to the recommended values for electrostimulation of fast motor fibers, thus, a frequency of $50Hz$ and a pulse width of $500\mu s$ were used for all channels. Finally, the amplitude of the signal varies in intervals of $2mA$ to find the necessary electrical current of activation of each channel.

2.2 Electrodes

For each protocol, different electrode sizes and number of channels were used. For the proposed protocol, six $5x5cm$ surface electrodes were used for three electrostimulation channels, while for the traditional method, two $5x9cm$ surface electrodes composed a single channel.

2.3 Inertial Measurement Unit (IMU)

The 3-Space Sensor system from Yost Labs was used for measuring the amplitude of the movement, it integrates gyroscope, accelerometer and magnetometer, providing spatial orientation and angular speed information in real time. The device was attached to an elastic ankle support and returns the angle of the leg relative to the initial setup.

2.4 Elastic Setup

In order to avoid instability and request greater muscle activation, a simple elastic setup was built. The apparatus consists of a seat where the patients feet can't reach the floor. As the foot of the stimulated leg hangs, in a rest position, an elastic connects the ankle and the back of the seat, with little tension applied. This setup will prevent the knee from extending abruptly and fully, preventing lesion and discomfort.

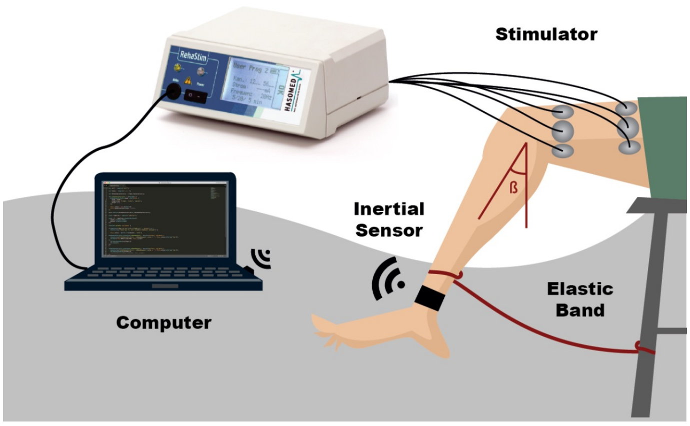

Figure 1. Experimental FES system. Both stimulator and inertial sensor communicate with a PC, in which the proposed protocol is implemented.

3. METHODS

In order to validate the presented method for channel selection, experiments were performed counting repetitions for both a standard protocol for FES and the discussed approach. The following sections describe the experimental setup and the FES protocol utilized for validation.

3.1 Electrodes Disposal

Electrodes were disposed on the anterior portion of the thigh, aiming for the quadriceps, in order to cause knee extension. They were positioned in accordance with each protocol, as follows.

3.1.1 Standard Protocol

In the traditional method, a single channel was used with two large $5x9cm$ electrodes arranged transversely in the user's upper and lower thigh. Adjustments to placement could be made in order to get optimal muscle response.

3.1.2 Channel Selection Protocol

In the proposed method, three channels delivering current through six small $5x5cm$ electrodes were similarly disposed in the upper and lower portions of the thigh. There was no adjustments or correction in placement, so the system can deal with a supposed imperfect positioning.

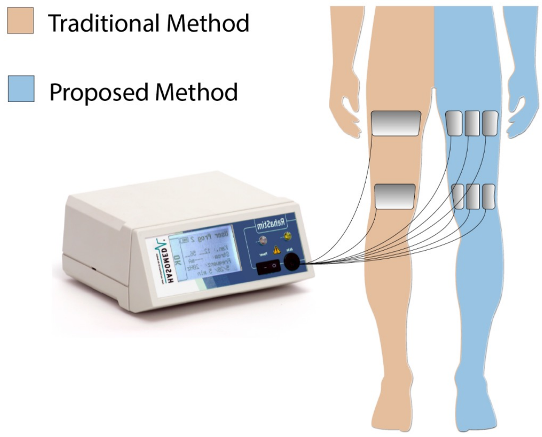

Figure 2. Electrodes positioning for both the channel selection protocol and the control data. On the left is represented a traditional disposal of two $5x9cm$ surface electrodes. The right side represents the proposed disposition of two arrays of three $5x5cm$ surface electrodes.

3.2 Stimulation Parameters

Stimulation parameters used throughout the experiments are disposed on Tab (1). Electroestimulation pulse, wave frequency and pulse width remains the same for all protocols. The pulse height, or electrical current amplitude may vary from a minimum of $10mA$ to a maximum of $30mA$, through steps of $2mA$

Table 1. Stimulation parameters utilized in channel selection, stimulation protocol and standard protocol. Only the pulse amplitude was controlled in the proposed protocol, the remaining parameters were constant throughout the experiments.

	Wave Type	Frequency	Pulse Width
FES Parameters	Bipolar Square Wave	$50Hz$	$500ms$

3.3 Channel Selection

Slight changes in electrode position often cause great variation in muscle selection and activation, resulting in different contributions on the knees single degree of freedom. The first step of the channel selection process is finding channels that most significantly contribute to the analyzed movement, and relating them to the minimum stimulation that causes a predefined response threshold. For this task, a program was developed. It scans throughout the placed channels and stimulates each individually within a range of custom predefined electrical current values in steps of $2mA$, while measurements are taken from the IMU sensor.

When the channel stimulation causes knee angle variation greater than a given threshold, $30°$, channel and electrical current are stored and removed from the next scan routines. Channels that reach the maximum electrical current are classified as unable to be used. Patient and therapist are also able to remove any channels along the experiment if necessary, due to discomfort or as required. The scan procedure continues as far as all channels are either stored or removed. Table (2) briefly summarizes the stimulation parameters used during channel selection.

Table 2. Channel selection parameters. When IMU information of leg extension overcome the Goal Angle, the channel is selected and electrical current information stored. The values of i_min and i_min represent the range in which the electrical currents amplitude may vary during channel selection. Parameter i_step is the value added to the electrical current at the end of each loop.

	Goal Angle	i_min	i_max	i_step
Channel Selection Parameters	$30°$	$10mA$	$30mA$	$2mA$

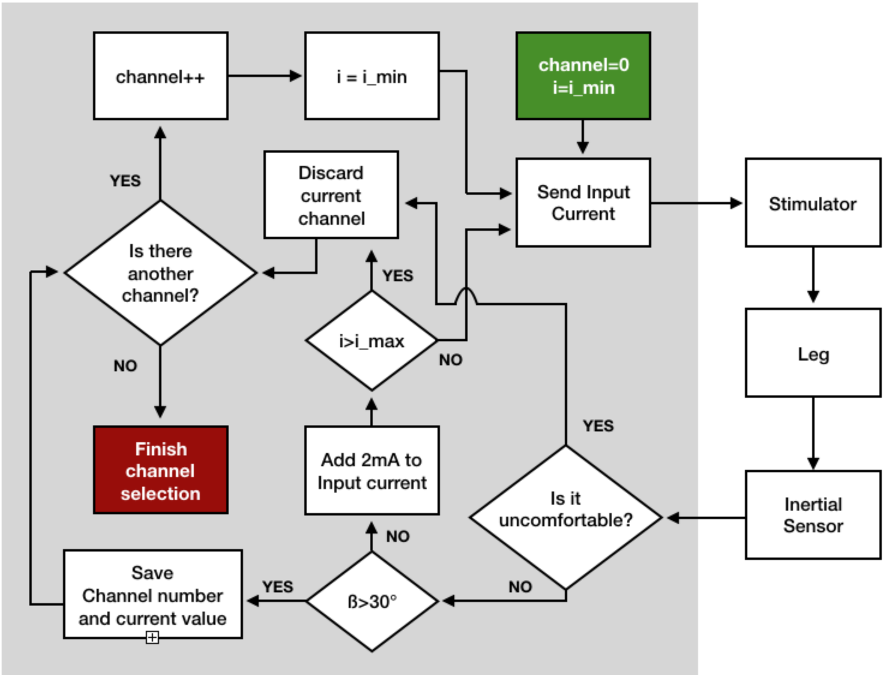

Figure 3. Proposed algorithm for channel classification and sorting. Its parameters are shown in Table (2). For each channel disposed, it performs the electrical stimulation with electrical currents varying from i_min to i_max. When the knee movement angle reaches 30°, this channel and its current are stored. Channels can also be discarded when their electrical currents reach i_max, or if they're uncomfortable. The algorithm finishes when all the channels are either stored, or discarded.

3.3.1 FES Protocol

With the data collected in the previous step, a stimulation protocol aims to illustrate and validate the method. It assumes the electrodes remain in the same position as they were tested previously.

The routine consists in the activation of one channel at the time, using the electrical current channel relation data. It starts from the most sensible (smallest electrical current) channel, stimulating it for one second, measuring the highest knee angle variation for analysis. The routine continues until the angle measured is below 20°, when it skips the current repetition counting and moves on to the next smallest electrical current channel.

Once finished, the protocol returns the total number of repetitions and repetitions per channel.

3.4 Standard Protocol

In order to compare results, repetitions of a more traditional electrode placement method were counted. The following method is the approach used by therapists.

In this protocol, a single pair of electrodes is carefully placed, by trial and error, on the spot where the stimulation is found to cause the greater muscle response. Following, the channel is calibrated to the smallest electrical current able to cause 30° angle variation. Every other stimulation parameter is kept unchanged. This data is sent to the stimulation protocol so it runs the same routine as previously explained, but this time, with a single best channel.

Number of repetitions is collected so it can be compared to the previous protocol, as a control dataset. The results of this standard protocol will be called Control Data.

4. RESULTS

Tests were performed in two subjects, both authors of this article. Table (3) and Tab. (4) states the results for two testing sessions. One of their legs was subjected to the channel selection and the stimulation protocol, while the other leg has was subjected to the traditional method. Comparative results are referred to the same patient, assuming symmetrical and equally strong legs, as an attempt to minimize the difference between the limbs analyzed with each method. The

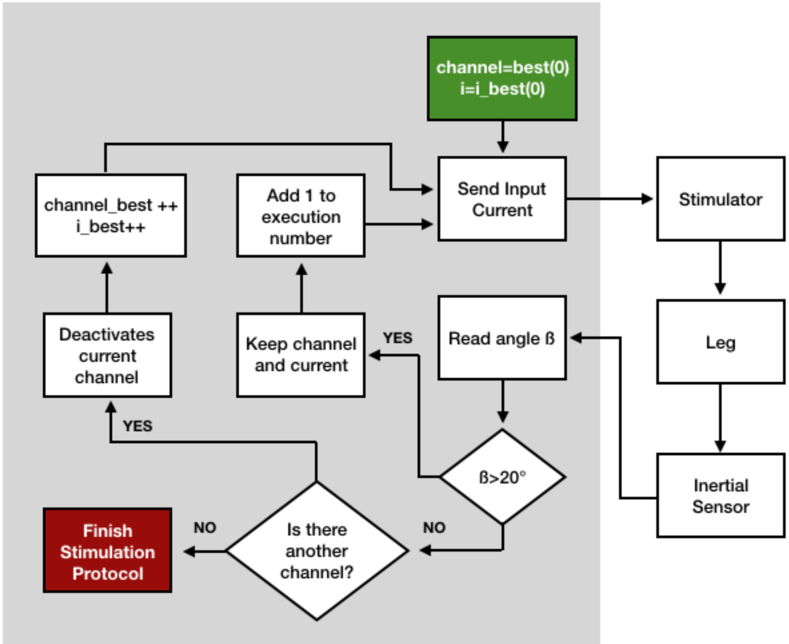

Figure 4. Fluxogram of the functional electrical stimulation protocol used to validate the channel selection approach. Consists in a routine of stimulation for each of the channels selected by figure 3. For each repetition, the maximum angle of movement is recorded. When the angle measured is below 20°, the protocol switches to the next channel. As a result, the number of repetitions performed by each channel is recorded.

corresponding electrical currents and repetitions for each channel selected and the control data are disposed on the tables. The total column exposes the sum of repetitions of the proposed electrical stimulation protocol.

Table 3. Stimulation results for patient 1. Described protocol was performed first. The channel selection and stimulation protocol was performed on his dominant leg. The table relates the amplitude current of each electrode to the repetitions on knee extension exercise. Control data states for the standard protocol results on the non dominant leg.

Patient 1	Channel 1	Channel 2	Channel 3	Total	Control Data
$I_{pp}(mA)$	*	20	20	-	22
Repetitions	0	11	38	49	33

* Removed due to uncomfortable placing.

Table 4. Stimulation results for patient 2. The standard protocol, control data, was performed on his dominant leg. The table relates the amplitude current of each electrode to the repetitions on knee extension exercise. The channel selection and stimulation protocol were performed on the non dominant leg.

Patient 2	Channel 1	Channel 2	Channel 3	Total	Control Data
$I_{pp}(mA)$	28	*	22	-	22
Repetitions	19	0	45	49	26

* Removed due to uncomfortable placing.

When comparing the results of the channel protocol and standard protocol on both tables Tab. (3) and Tab. (4), it's observed an larger number of repetitions. In addition, note that a single channel of the stimulation protocol, channel 3 on both subjects, performed more repetitions than the entire standard protocol. Those results indicate that covering a wider surface on many electrodes may result in a better performance on the knee extension exercise, when compared to a trial and error standard approach.

5. CONCLUSION

This paper proposes a facilitated setup on FES electrodes disposal for knee extension exercise. Upon a non-standard electrodes disposal, an automated channel selection extracts the best electrical currents to perform the exercise for each channel. Then, a simple stimulation protocol performs the exercises and counts the repetitions. According to the results of both subjects, Tab. (3) and Tab. (4), the channel selection and stimulation protocol achieved a larger number of repetitions when compared to the standard protocol.

Observe that on both subjects, only two of the three electrodes were used for channel selection and stimulation protocol. Uncomfortable electrode placing is still a limitation of the discussed approach. Even better performance may be achieved if all three electrodes are placed in comfortable positions. The number of appropriate electrodes selected may also increase with a greater number of channels.

Even though the scope of this paper is not muscular fatigue specifically, results show an improved performance on the knee extension exercise repetition. Thus indicating that the preset method for electrodes channel selection may not only facilitate the electrodes disposal, but also improve the exercise performance prior to muscle fatigue.

On future developments, its expected to perform a wider study, with more subjects and more electrode channels available for selection and stimulation. Validating this approach with actual SCI patients is also essential to fulfill this paper perspectives. If the results remain consistent, the proposed method for channel selection may be explored with different stimulation protocols and different rehabilitation exercises.

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8. RESPONSABILITY FOR THE INFORMATIONS

The authors are the only responsible for the information of this article.