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Identification of Suitable Elements within Electrode Arrays for Drop Foot Stimulation

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Introduction

The correct placement of stimulation electrodes is one of the most crucial parts for transcutaneous functional electrical stimulation (FES). Electrode arrays with a large amount of smaller stimulation elements are proposed to solve this issue. A common hydro gel layer is applied between the electrode array and the skin. The smaller elements can be dynamically connected with the stimulation channel, to form a so-called virtual stimulation electrode. In order to identify the best size and shape of a virtual electrode, identification algorithms are used. For the BMBF funded project AParo-Stim (Adaptive Peroneus Stimulator), four algorithms are compared in order to find a good compromise between the time needed for identification and quality of the stimulation induced foot movement. The identified virtual electrodes will be used for prolonged, gait phase driven stimulation later on in the project.

Methods

The experimental set-up consists of two electrode arrays, a 4x6 element array over the area of the tibialis anterior muscle, and a 3x10 element array over the area of the peroneal nerve. The dorsiflexion and eversion angle of the foot are measured with two inertial sensors on the foot and shank in order to assess the quality of the induced foot movement. Monophasic stimulation pulses are used for the identification procedure.

As a first step, single element stimulation intensities which produce sufficient foot movement are identified for both arrays. These stimulation intensities are applied afterwards for all four algorithms. The first algorithm used (A) is a brute force approach, where each element is stimulated separately. The result of this algorithm serves as a reference for the other algorithms. The second algorithm (B) is a quick sort type algorithm. The electrode array is divided step by step into smaller virtual electrodes until only a single element remains. The third algorithm (C) is a gradient method. The fourth algorithm (D) is also a brute force approach, but looking for the best virtual electrodes with 2 or 3 elements instead of searching the best single element. All algorithms use a stimulation protocol with 0.5 seconds stimulation and 1.5 seconds rest in which the foot drops back to the resting position. The entire process is done for both electrode arrays separately while the whole non-investigated array served as large counter electrode.

Results

The four identification techniques were tested on 5 healthy subjects (22 to 27 years old). The usage of monophasic stimulation pulses splits the identification process into two independent problems. This reduces the complexity of the identification process from an O(24*30) problem to an O(24+30) problem.

The brute force algorithm (A) took the longest time (108 seconds in average), but always produced a reliable rank list of suitable elements. The algorithm B was significantly faster (35 seconds in average), but could not always find the best single element according to A. The algorithm C always found the best single element according to A, if the start element was in the vicinity of the best element. Information from the search for the stimulation intensities could be used to select such a start element. The time needed for C to complete depends mostly on the selected start element. The best case scenario (start element is the best single element) terminates in 28 seconds. The identification algorithm D required a total of 44 seconds to complete the identification. The found virtual electrode included the best single element identified by A or was a direct neighbour of it.

Conclusions

The experimental results prove that monophasic stimulation pulses can be used to greatly simplify the identification process. Furthermore, four identification algorithms were introduced and compared. The gradient-based algorithm C promises the quickest accurate identification of the array element which produces the best quality of foot movement, as long as the start element is chosen within the vicinity of the best element. A strategy on how to choose the start element was also discussed.