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Method for Blink Detection in Single Channel of Invasive Electromyogram Signal

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Problem statement. Facial nerve damage is the cranial nervous system disorder often leading to facial muscle paralysis, which might be effectively restored using functional electrical stimulation of the fully or partially denervated circular muscle of the eye to achieve muscle contraction to close the eyelids. To control the invasive stimulation system, the automated detection of the blink event in the intact eye is used as a trigger. To achieve this, the new approach to single channel invasive electromyogram (EMG) signal analysis is proposed. **Materials and Methods**. The combined time-spectral approach to blink detection consists of the two stages, starting from the thresholding of filtered EMG signals in the sliding window, which is followed by comparing the total spectral power in the Fourier domain to minimum and maximum thresholds. If both conditions are met, the EMG in the current window is considered to contain the blink event. In the experiment, the EMG data recorded from the one male adult healthy volunteer is used, the signal contained an acceptable amount of artefacts and was recognized as reflecting the usual EMG. The true positive rate (TPR), positive predictive value (PPV), False Discovery Rate (FDR), and False Negative Rate (FNR) is used as a performance metrics. **Results**. In the result of applying the proposed blink detection algorithm with 500 ms duration of the time window and 100 ms overlap, the following performance metrics are obtained: TPR = 93%, PPV = 63%, FDR = 7%, FNR = 37%. **Impact**. Acceptable true positive rate of blink detection suggests the method is promising for wider applications in the clinical settings and might be incorporated in the prototypes of implanted systems for facial muscle paralysis restoration using functional electrical stimulation for further development.

Key words: electromyography, facial nerve paralysis, blink detection

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Introduction

Facial nerve (FN) damage is one of the most common disorders of the cranial nervous system, which often leads to facial muscle paralysis [1, 2]. The consequence is inability to close the eye, resulting in corneal atrophy and vision loss. This often cannot be effectively restored with surgical interventions, neither with mechanical springs, weight of the upper eyelid increase, muscle transpositions. In several studies [3–6], the usability of functional electrical stimulation (FES) of the fully or partially denervated circular muscle of the eye (CMO) to achieve near-physiological muscle contraction is proposed [7,8] as an promising alternative possibility of closing the eyelids.

To drive the automated implantable system for CMO stimulation, the blink in the intact eye is used as a trigger. To that aim, the closed-loop system should continuously monitor the neural or myographic activity on the undamaged side, and in case of blink event it should be detected and the appropriate control signal is to be sent to trigger the CMO stimulation for eye closure on the damaged side. To implement this operation, the electromyogram (EMG) signal from either the implanted or surface electrode should be measured and continuously processed in near-to-real time with blink detection algorithm.

The real-time algorithms for blink detection are not well developed at the moment. In the work [9] the simple peak detection is applied to the EMG signal, and the increasing of the static threshold serves as a trigger for the stimulation, which is very prone to false triggering due to noise and artefacts. No metrics of the algorithm performance are reported. In [10], the multichannel surface EMG is analyzed with a custom amplitude-based or slope-based suprathreshold activity detector, applied to each channel independently. Despite promising, the direct application to the single-channel EMG from implanted electrodes is not straightforward. Combination of the time-domain EMG amplitude analysis with the spectral-domain power analysis in the predefined frequency range is proposed in [11] using the constant thresholds, demonstrating the acceptable performance in the implantable system.

Parallel to the methods relied solely on the invasive EMG, there are other approaches to eye blink detection, such as based on combined analysis of electroencephalogram (EEG) and electrooculogram (EOG) for assistive communication tools [12], for controlling the wheelchair [13], and driver drowsiness detection [14]. Despite quite elaborated algorithms which are proposed therein, they do use surface signals for blink detection, which are not directly transferrable to invasive EMG due to different signal properties.

In our work, the combined time-spectral approach to blink events finding in single-channel invasive EMG is further developed, and the new method for blink detection is proposed and tested on recordings from healthy human subject.

1 Materials and Methods

1.1 Experimental data

In the experiment, the EMG data is recorded from the one male adult healthy volunteer (23 y.o.) in the Institute of Neurosurgery of Ukraine. The sampling frequency is 20 kHz; EMG spectral range from 0 to 300 Hz was selected for further analysis. In total, ~15 minutes of EMG was recorded, the signal contained an acceptable amount of artefacts and was recognised as reflecting the usual EMG. Before applying the proposed algorithm, EMG was filtered with $5th$ order Butterworth high-pass filter with 3 Hz cut-off frequency.

1.2 Method for blink detection

The combined time-spectral approach is grounded in the proposed algorithm for blink detection. The algorithm is presented in Fig. 1. First, the current time window i is selected in the filtered EMG signal $x_i[n]$ of N samples length. Standard deviation of the EMG is calculated as

$$STD = \sqrt{\frac{1}{N}\sum_{n=1}^{N}\left(x_i[n] - \overline{x_i[n]}\right)^2},$$

where $\overline{x_i[n]}$ is the mean value of the EMG in the current window. Then it is compared to the threshold STD_{th}.

If the standard deviation of the EMG in the current window is over the threshold, then the power spectral density PSD is calculated for the window i. Then, the total power is calculated and tested if it fits between two thresholds: minimum total power ($SP_{th\ low}$) and maximum ($SP_{th\ high}$). If both conditions are satisfied, then the blink is detected. This event will trigger the system to generate stimulation pulses. If either standard deviation is lower than the threshold (due to absence of the excessive activity with respect to background), or the spectral power is larger (e.g. due to artefacts) or lower (due to less powerful events than blinks), then the blink is absent in the current time window, and the next time window is being analyzed.

Since we adopt the subject-specific approach, the thresholds were experimentally tuned to reach the best performance. Three thresholds are to be empirically optimized in the laboratory settings to yield the highest performance of the implantable device for each particular subject. In clinical applications they should either be computed from population studies, or adaptively selected for each subject in the patient-specific settings.

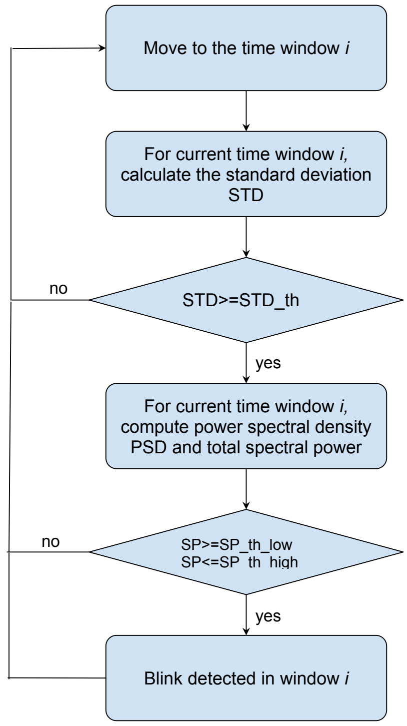

Fig. 1. Proposed algorithm for blink detection

To evaluate the performance of the proposed algorithm in the experiment, true positive rate (TPR) and positive predictive value (PPV) were used. True positive rate (Sensitivity) is the ratio of correctly identified blink to all blinks presented in the EMG. Positive predictive value is the ratio of correctly identified blinks to all signal fragments identified as blinks (both correctly and incorrectly). Based on these two metrics, False Discovery Rate (FDR) is calculated as 1-PPV, and False Negative Rate (FNR) is calculated as 1-TPR, to additionally describe the performance of the algorithm.

2 Results

The example of the EMG signal with marked blink events is presented in Fig. 2. A typical blink lasts approximately 300 ms, so 500 ms duration of the time window is selected with 100 ms overlap.

In the result of applying the proposed blink detection algorithm, the performance metrics are obtained for a range of the algorithm thresholds. After tuning the

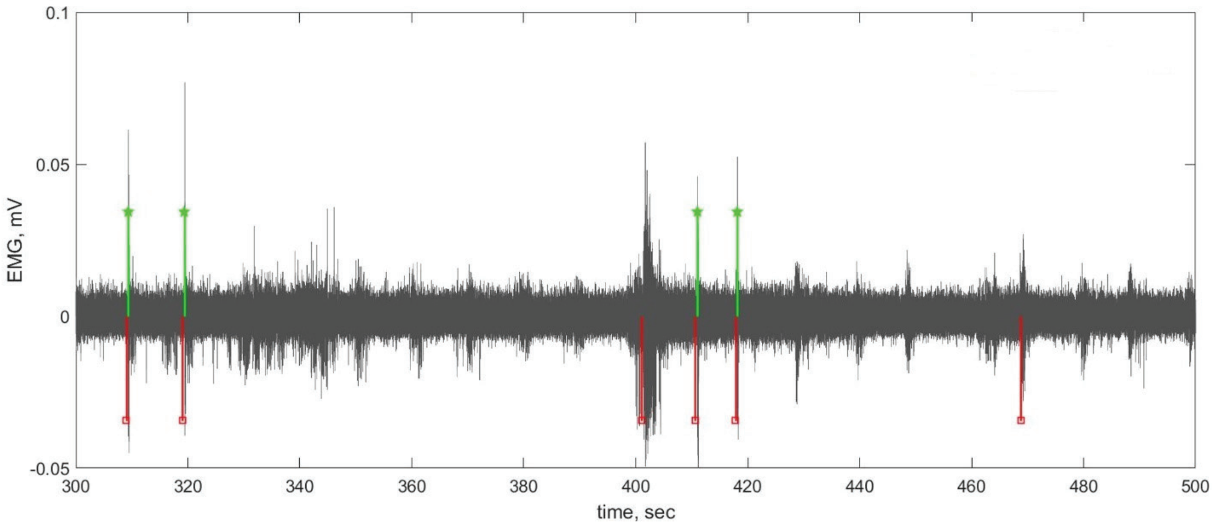

Fig. 2. Example of the EMG signal with marked events of the blinks (stems with red squares) and results of the blink detection using the proposed algorithms (stems with green stars) [12]

algorithm parameters, the following best metrics are obtained (see Table 1).

Table 1 Blink detection performance metrics

Metric	Value, %
True positive rate (TPR)	93
Positive predictive value (PPV)	63
False discovery rate (FDR)	37
False negative rate (FNR)	7

True positive rate is acceptable and false discovery rate of the erroneous blinks is low, which is promising for real-life applications and natural conditions for triggering the blinks synchronously for both sides of the face. At the same time, quite decent positive predictive value suggests that there is the room for improvement of the algorithm. First of all, more experimental data is required to understand the approach to selection of thresholds both in time and spectral domains. Also, the preprocessing of EMG signal will potentially improve the blink detection quality by removing the artefacts (such as head movement, chewing, swallowing, etc.)

Conclusions and Outlook

The new method for detecting the blinks in single-channel EMG is proposed, based on the combined time and frequency domain thresholding approaches. Its application on the EMG collected from the human subject is presented, resulting in an acceptable true positive rate of detection, which is promising for wider applications in the clinical settings.

The method was tested in one single subject due to the limitations in the collection of clinical data, hence this work should be considered as a feasibility study, which prepares the road to wider studies with recruiting more participants. Nevertheless, current results could be considered as encouraging: the proposed algorithm is able to detect the eye blinks in close-to-real settings with acceptable accuracy.

On the other hand, our current idea is the patient-specific settings, where the parameters of the algorithm are tuned manually by trials and errors for each user. The main reason for this is highly variable appearance of the signals from circular muscle of the eye, which depends both on the implanted electrode positioning and the anatomy of the face muscles. In favor of the current experiment setup with subject-specific algorithm parameter tuning speaks the fact that in implantable systems all parameters are being tuned for each user. Hence the future system should be fine-tuned for each subject, and the current findings are the example of its possibility. From the clinical perspective, such tuning of the parameters is acceptable, since in practice parameters of the implantable devices are selected for each user by the team of medical doctors and engineers.

In future, after the substantial database of the annotated signals is collected, we will work on the non-subject specific algorithms, if we can catch the common patterns in invasive EMG, including those based on the machine learning.

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Метод детекції моргання в одноканальному сигналі інвазивної електроміограми

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Пошкодження лицьового нерва - це розлад черепної нервової системи, який часто призводить до паралічу м'язів обличчя, який можна ефективно відновити за допомогою функціональної електричної стимуляції повністю або частково денервованого кругового м'яза ока, щоб досягти скорочення м'язів для закриття повіки. Для управління системою інвазивної стимуляції в якості пускового механізму використовується автоматичне виявлення події моргання в неушкодженому оці. Для цього в роботі запропоновано новий підхід до аналізу одноканального сигналу інвазивної електроміограми (ЕМГ).

Комбінований часово-спектральний підхід до виявлення моргання складається з двох етапів, починаючи з порівняння з порогом відфільтрованих ЕМГ-сигналів у ковзному вікні, за яким слідує порівняння загальної спектральної потужності в області Фур'є з мінімальним та максимальним порогами. Якщо виконуються дві умови, вважається, що ЕМГ у поточному вікні містить подію моргання.

В експерименті використовуються дані ЕМГ, записані від одного дорослого здорового чоловіка-добровольця; сигнал містив прийнятну кількість артефактів і визнаний таким, що відображає звичайну ЕМГ. Чутливість (TPR), позитивне прогнозне значення (PPV), коефіцієнт помилкового виявлення (FDR) та хибно-негативний коефіцієнт (FNR) використовуються як показники ефективності.

В результаті застосування запропонованого алгоритму виявлення моргання з тривалістю часового вікна 500 мс та перекриттям 100 мс отримані такі показники ефективності: TPR = 93%, PPV = 63%, FDR = 7%, FNR = 37%.

Прийнятна чутливість виявлення моргання свідчить про те, що метод є перспективним для більш широкого застосування в клінічних умовах і може бути застосований у прототипах імплантованих систем відновлення паралічу м'язів обличчя за допомогою функціональної електричної стимуляції для їх подальшого розвитку.

Ключові слова: електроміографія, параліч лицьового нерву, детектування моргання

Метод детекции моргания в одноканальном сигнале инвазивной электромиограммы

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Повреждение лицевого нерва - это расстройство черепной нервной системы, которое часто приводит к параличу мышц лица, который можно эффективно восстановить с помощью функциональной электрической стимуляции полностью или частично денервированной круговой мышцы глаза, чтобы добиться сокращения мышц для закрытия века. Для управления системой инвазивной стимуляции в качестве пускового механизма используется автоматическое обнаружение события моргания в неповрежденном глазу. Для этого в работе предложен новый подход к анализу одноканального сигнала инвазивной электромиограммы (ЭМГ).

Комбинированный временно-спектральный подход к выявлению моргания состоит из двух этапов: сравнение с порогом отфильтрованных ЭМГ-сигналов в скользящем окне, за которым следует сравнение общей спектральной мощности в области Фурье с минимальным и максимальным порогами. Если выполняются три условия, считается, что ЭМГ в текущем окне содержит событие моргания.

В эксперименте используются данные ЭМГ, записанные от взрослого здорового мужчины-добровольца; сигнал содержал приемлемое количество артефактов и признан отражающим обычную ЭМГ. Чувствительность (TPR), положительное прогнозное значение (PPV), коэффициент ложного обнаружения (FDR) и ложно-отрицательный коэффициент (FNR) используются как показатели эффективности.

В результате применения предложенного алгоритма обнаружения моргания с продолжительностью временного окна 500 мс и перекрытием 100 мс получены следующие показатели эффективности: TPR = 93%, PPV = 63%, FDR = 7%, FNR = 37%.

Приемлемая чувствительность обнаружения моргания свидетельствует о том, что метод является перспективным для более широкого применения в клинических условиях и может быть применен в прототипах имплантированных систем восстановления паралича мышц лица с помощью функциональной электрической стимуляции для их дальнейшего развития.

Ключевые слова: электромиография, паралич лицевого нерва, детектирование моргания