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A new evolutionary approach for neural spike detection based on genetic algorithm

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ABSTRACT

Identification of the epileptic features in nervous signals is one of the main goals of neuroscientists and biomedical engineers since it provides valuable information about the current and future health status of a patient. Implantable wireless neural signal recording is a powerful, newly emerging technique that has been suggested for neural signal tracking and recording. One of the main issues with this technique is the transmission of enormous amounts of data, which requires high bandwidth and high power consumption for the implanted device. Neural spike detection and spike sorting can be used to reduce the power consumption and the amount of data transmitted. Neural spike detection is a challenging technique because of the large amount of background noise that exists in the body known as low potential field signals (LPF). Existing signal processing methods make use of amplitude thresholding and artificial neural networks to recognize spike signals, but are very vulnerable to noise and require a large amount of pre-training before being useful. Nonlinear energy operators (NEO) are also used to filter spike signals from this background noise. This method requires precise selection of a particular coefficient that is currently chosen by human intervention, which is time consuming and open to human error. In this work a novel approach utilizing a genetic algorithm (GA) based on a nonlinear energy operator (NEO) is proposed. The proposed expert system uses a GA to automatically adjust the threshold level in the NEO technique to detect the spike within a noisy signal in real time. The method is able to recognize the number and the location of spike-events in a neural signal in real time. Preliminary simulations show that the genetic algorithm gives superior results to the manual selection method, and that the improvement is more pronounced in noisier signals.

1. Introduction

Studying and monitoring the neural activities of the human brain has become one of the most interesting and challenging fields of biomedical engineering for neuroscientists and electronic engineers. This technology promises to be able to extract useful information from the nervous system which could benefit various kinds of patients, such as empowering amputees to control advanced prosthetic limbs. Medical application of extracellular recording has been demonstrated for the treatment of epilepsy, paralysis and other disorders as well. Additionally, neural activities can be used for brain computer interfacing (BCI) systems.

Currently, neural probes with more than 1000 arrays are used to record neural activities inside the brain (Yang, Hoang, Zhao, Keefer, & Liu, 2011; Zarifi, Chung-Ching, & Zarifi, 2011). The firing of thousands of neurons causes the electrical activity along the scalp, but the mixture of these activities with noise causes neural spike detection be a complicated issue (Keshri, Sinha, Singh, & Das, 2011; Othman, Shaker, & Abdullah, 2005). Furthermore, signal transfer from neuron to electrode can be weak and may reshape the amplitude of the signal because of the transfer path characteristics (Smith & Mtetwa, 2007).

The first step in studying and processing neural signals is to detect action potentials among various noise sources and the brain's background activities. The action potentials are generally known as spike signals and demonstrate physical activities either in the brain or in the organs. Within the area of neuroscience and neural prosthetics applications, spike detection plays an important role since it could help to reduce the amount of transmitted data and the error that can be caused by adjacent cells. Fig. 1 shows a block diagram for an implantable neural signal recording system and the preprocessor that detects the neural spikes, sorts them, and reduces the dimension of the transmission data.

To create a practical device, the system would be required to operate in an electrically noisy environment where spike signals can be difficult to detect. The device would also need to adapt

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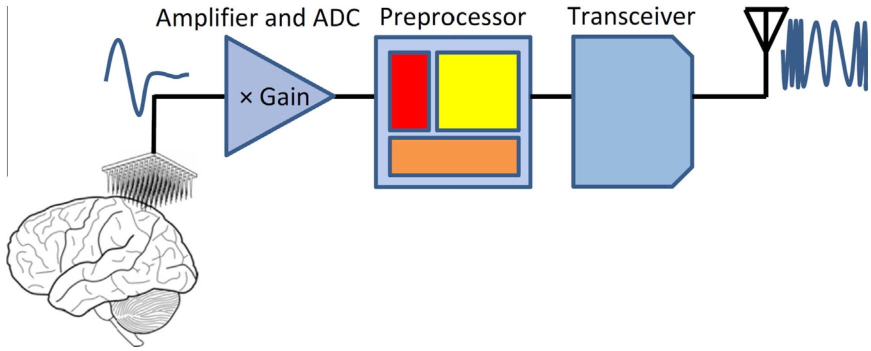

Fig. 1. Implantable neural signal recording system.

independently to changing environmental factors without human intervention.

To detect spike signals in noisy environments, there are currently various algorithms with their own advantages and drawbacks (Ko, Lin, Chung, & Jan, 1998; Mukhopadhyay & Ray, 1998; Nenadic & Burdick, 2005; Peng, Sabharwal, & Bashirullah, 2009; Zarifi, Frounchi, Tinati, Farshchi, & Judy, 2011). Conventionally, neuroscientists extract the feature of neural signals manually (Haydari, Zhang, & Soltanian-Zadeh, 2011). Although these experts are skillful, the nature of experimental situations can cause false results. Moreover, neural signal investigation by human intervention is time consuming (Haydari et al., 2011; Wilson & Emerson, 2002); therefore, automatic methods have been proposed to detect the spike signals. It is notable that most of the existing automatic techniques for spike detection need initial patient training on strong processors located out of the patient's body (Othman et al., 2005).

Several automated processing techniques have been introduced and applied to spike detection systems. The most popular and widely used technique is amplitude thresholding. This technique simply relies on the amplitude of the received signal without any pre or post processing. This technique is attractive because of its simplicity and ease in hardware implementation, but is vulnerable to noisy signals (Harrison, 2003; Smith & Mtetwa, 2007). Artificial neural networks (ANN) are the other alternative for adaptive spike signal detection. ANN methods are used in different areas of biomedical signal processing and efficiently improve the detection algorithms but they have the drawbacks of pre-training and difficult hardware realization (Chandra & Optican, 1997; Nia, Shogian, & Zarifi, 2008).

There are other algorithms based on the energy of the signals for spike detection. These techniques consider that within the same time intervals, the energy of the spike is greater than that of the noise (Liu, Yang, & Zheng, 2012). One of the popular and simple methods to extract a spike signal out of a noisy signal is a nonlinear energy operator (NEO) which is based on the energy disparity between spike and noise in a sample interval. Since this technique demonstrates high efficiency and accuracy in detecting the action potentials, and because of its simplicity, it gathers more attention than other methods. In this method, a semi-constant coefficient is used to scale the threshold. The accuracy of this method is strictly dependent on accurate selection of that coefficient.

In this work, a novel, reconfigurable technique based on a genetic algorithm (GA) is introduced that uses the NEO method as the core algorithm for spike signal detection and adds dynamic adjustability to threshold level in this method. Genetic algorithms also have the advantage of continuously adapting independently to changing conditions without human intervention. The GA incorporated NEO method is more robust in detecting spikes in noisy signals than the conventional methods, is fully automatic, and does not require any prior information about spike shape, or maximum or minimum level of the spike signal.

A comparison to conventional methods is presented to find the optimum value of this constant coefficient – so called *C*. GA, which is inspired from natural evolution, is able to handle the large search spaces (Chandra & Optican, 1997). The advantage of utilizing a GA based approach over conventional methods is the ability to determine the *C* factor automatically in various different situations and make it independent of the experimental conditions.

This paper is organized as follows: in Section 2 a background of the NEO method and data acquisition method are presented. The paper continues with a brief description of GA and a presentation of the proposed method in Section 3. In Section 4 the effectiveness of the GA based method is studied with simulations, and finally the conclusions are drawn in Section 5.

2. NEO method for spike detection

The energy and frequency of neural spikes are two important parameters for spike identification in a noisy neural signal. In NEO techniques, energy of different samples is calculated and compared to detect the spike. It consists of two basic steps: First is to deploy a nonlinear function $\psi[n]$ to sort the samples with their instantaneous energy and frequency as Eq. (1) shows:

$$\psi[n] = x^2[n] - x[n+1]x[n-1] \tag{1}$$

where $x[n]$ is the sample of signal at time n and $\psi[n]$ is the NEO operator (Smith & Mtetwa, 2007). The second step is to define a threshold value and compare it with the signal. Eq. (2) shows the acquisition of the threshold value:

$$\text{Threshold} = C \times \frac{1}{N} \sum \psi[n] \tag{2}$$

where N is the length of the signal and C is a coefficient that scales the threshold, which the accuracy of the NEO is strictly dependent on.

Since the C factor plays such an important role in detecting neural spikes in a sample signal, it is very important to determine it accurately. As this C factor could change from one experiment to the other because of its dependency on noise and recording conditions, it's possible to obtain two different C values for the same measurement at different times.

Receiver Operating Characteristic (ROC) curves have generally been used to find the desired C factor. Experimental and trial-and-error methods have also been used to find an optimum value for the C factor (Harrison, 2003; Nenadic & Burdick, 2005). For real time detection of the spike signals using NEO techniques, the conventional experimental methods for optimizing the C factor are not