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# A simple method for efficient spike detection in multiunit recordings

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**Abstract**

A number of spike detection and sorting methods exist and the availability of powerful desktop computers may suggest that the problem of spike detection is solved. However, for portable multi-channel systems, when one takes into account the power consumption limitations, computationally simple methods can be advantageous when compared to more complex algorithms. Here we describe a simple spike detection method that reduces approximately two-fold the rate of false detections compared to the single threshold spike detection method. The proposed algorithm can be employed in an analog electronic chip thus eliminating the need for the digitization of the original signal. Consequently, only the times of spike occurrence can be transmitted for further analysis.


*Keywords:* Extracellular recordings; Multiunit recordings; Multichannel recordings; Brain machine interface; Prosthetic devices; Spike detection; Spike sorting

## 1. Introduction

Multiple electrodes are now a standard tool in neuroscience research allowing to study the simultaneous activity of several neurons in a given or across different brain regions (Brown et al., 2004; Super and Roelfsema, 2005). The introduction of improved real time analysis of data from multiple electrodes has enabled the demonstration that the activity of central neurons can directly control the movements of robotic arms or computer cursors (Nicolelis, 2003) and prosthetic devices based on such a principle are already undergoing the first clinical trials (Cyberkinetics, http://www.cyberkinetics.com). In such prosthetic devices, motor commands are derived from information encoded in the arrival times of action potentials (APs) obtained by multi-electrode recordings in motor areas of the cortex (Carmena et al., 2003). For mobile and compact prosthetic devices, the AP detection has to be performed with limited computational resources requiring relatively simple algorithms. In fact, a recent study has shown that, for compact mobile multichannel systems, simple AP detection algorithms perform relatively well when factors such as computational power and digitization speed are taken into account (Obeid and Wolf, 2004).

Here we propose a new simple algorithm of spike detection based on the synchronous evaluation of peak and trough of the extracellularly recorded AP (Italian patent application BG 2006A 00001). We tested our method with real averaged APs embedded into the realistic noise signal. Simulations showed that, compared to the usual single threshold method, the proposed two-threshold method reduced two to four times the rate of falsely detected APs while very few APs are missed.

## 2. Methods

The spike detection algorithm is based on the simultaneous detection of the peak and trough of the spike, and is schematically shown in Figs. 1 and 2. Two thresholds are used for the detection of a spike: a positive threshold ($D$), set to detect the spike peak, and a negative one ($C$), of lower amplitude, employed for the detection of the spike trough. A spike is detected only if the trough is detected within a period of time determined by the time-window generator ($E$) after the peak detection. Typical shapes of signals obtained at various positions of the circuit are shown in Fig. 2. Importantly, the trough detection occurs in a dedicated channel that has an additional low-pass filter, which will be discussed later. For simplicity, we will call the proposed algorithm that includes low-pass filtering for trough

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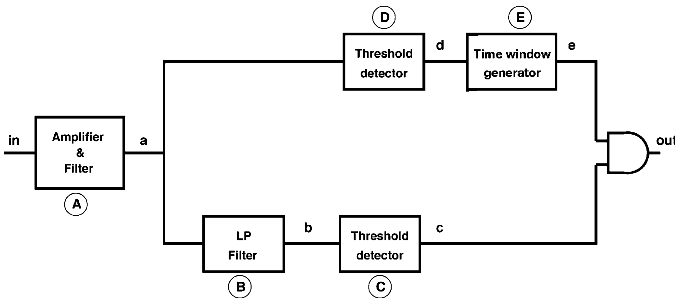


Fig. 1. Schematic block diagram of the method implementation.

detection the *two-threshold with filtering method.* Similarly, the same peak and trough detection without filtering will be called the *two-threshold method.* The parameters used for these two methods are given in Section 3.

Although both two-threshold methods are similar to the time-window spike sorting algorithms (Hidden and O'Boyle, 1979; Luscher et al., 1983), to the best of our knowledge, an additional filtering of the signal used for the trough detection has never been reported in the literature.

The input signal was obtained from four independent sources. The first set consisted of 30 APs isolated from *in vivo* motor cortex recordings from a rat, an owl monkey, and a macaque (Obeid and Wolf, 2004). The second set of 12 APs was attained from our recordings from cortical primary cultures employing a multichannel system MEA (Reutlingen, Germany). The third set (19 APs) was obtained from recordings *in vivo* in a macaque monkey at University of Ferrara, Italy. The fourth set of 15 APs was extracted from recordings in humans performed during the surgery to insert the stimulation electrodes for the deep brain stimulation. The examples of typical AP waveforms of different sources are shown in Fig. 3. The whole set of AP waveforms can be made available by contacting the authors of this paper. The sampling rate of these APs was always 20 kHz and, to obtain similar recording conditions, all spikes were band pass filtered digitally at 500–10,000 Hz.

The noise signal was obtained from a recording that did not contain any spikes and the same digital band pass filter was applied. The overall signal was then built by superimposing onto the noise level a series of non-overlapping APs, evenly spaced every 5.5 ms. For all AP waveforms, signal-to-noise ratio (SNR) was defined as a total peak to trough amplitude divided by $6\sigma$ (where $\sigma$ is the standard deviation of the noise). Simulations were separately run for each AP type, and the final result is an average over a population of 86 AP waveforms of a fixed SNR. Although for the most results presented here the noise signal did not include distant neuron noise (a correlated or "hash" noise (Fee et al., 1996)), we did perform tests with the correlated noise (see Section 3). These tests showed that correlated noise had no significant effects on the obtained results. The correlated noise was generated as it has been described by Obeid and Wolf (2004). The attained signal of distant neurons was mixed with the electrode noise with a ratio of 1:1 and the resulting signal was used to calculate the noise standard deviation.

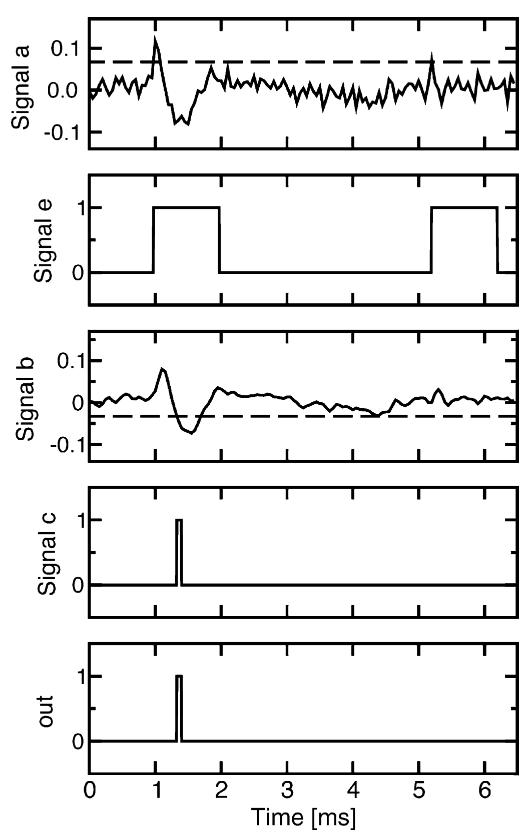


Fig. 2. Example signals for the two thresholds scheme with filtering algorithm (original signal SNR is 1.5, low-pass filter bandwidth is $B = 6$ kHz). Signal names refer to Fig. 1. Dashed lines in (a) and (b) represent the threshold values.

## 3. Results

We first estimated the additional computational complexity required by the two-threshold methods, assuming for simplicity a digital embodiment of the circuits. The detection process may require 1–2 preprocessor clock cycles, while the number of calculations required for the filtering procedure will depend on the type of filter adopted. Efficient digital filtering methods requiring few calculations have been reported (Paarmann and Atris, 2006). For example, if input data is sampled at 20 kHz, for a Bartlett-type 6 kHz low-pass filter used for simulations here, the estimated number of computer clock cycles would be around 10 (Mukhopadhyay and Ray, 1998). According to the cost function (CF) formula and the parameters used by Obeid and Wolf (2004), such an amount of calculations would reduce the cost function by around 0.4 points. Such a minor reduction in the score corresponds, for instance, to the reduction of the failure rate from 30 to 15 Hz that is achievable by the proposed method (see below). Thus, a higher reliability of AP detection can be sufficient to justify the increased method complexity.

To investigate the latter point, we first considered separately the rate of falsely detected APs and the overall performance was evaluated by plotting the receiver operating characteristics (ROC) graphs. We chosed the single threshold algorithm as the reference method because it has been shown to be relatively efficient for mobile multichannel systems (Obeid and Wolf, 2004).