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Assessing the effectiveness of Cepstrum of Bispectrum based spike detection on simultaneously recorded intra- and extra- cellularly recorded data

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Abstract

The new Cepstrum of Bispectrum based spike detection technique (*cob*) has shown excellent performance on simulated extracellular signals up to 0dB SNR (signal to noise ratio). But with real extracellular signal the *cob* sometimes does not perform as well as we demand with simulated signal. In this research, we assess the *cob* technique with 34 numbers of real extracellular signal whose ground truth was estimated from concurrent intracellular signals from the same target neuron. It is observed that the *cob* technique can detects target neuron's spikes with more than 80% accuracy even if the real extracellular signal has low SNR (nearly 0dB). The spike detection performance of both *cob* and the popular double-sided amplitude thresholded (DTL) technique have been accounted for comparison. We observed that the spike detection accuracy by *cob* outperforms DTL.

Problems of Finding Spikes in Extracellular Signal

Detecting and sorting of spikes from extracellular recordings is a challenging task as the electrode records signal from a huge number of surrounded neurons at a time where the spikes from few numbers of neuron are relevant to the task understudy and the rest of the neuron's signal contributes as a noise terms.

During an extracellular recording, the neurons closest to the electrode (target neurons) provide the largest signals at the electrode, but more distant neurons' action potentials are superimposed on the signal of interest and change its amplitude and shape. The activity of distant neurons appears as noise which may be highly correlated with the signal from target neurons. We seek to find action potentials from nearby neurons.

Difficulties inherent in spike detection in the extracellular signal:

(a) Neural spikes appear randomly.

(b) Spikes in an extracellular signal are not always of significantly higher amplitude than the noise.

(c) Extracellular electrode/target neuron geometry differs between neurons resulting in different shapes of spike.

(d) Different neurons' spikes may be superimposed.

(e) The overall shape of spikes changes due to neural noise (sum of signals from surrounding distant neurons)

(f) The surrounding neurons' spikes are an element of the noise in the extracellular signal and hence the noise may be similar to the target neurons spike shape (thus misleading the detection procedure).

Spike Detection Algorithms - Traditional and Advanced Techniques

Traditional Technique for Spike Detection:

It is generally assumed that the active neuron delivers signal (spike) with a higher amplitude than the other inactive neuron's signal (known as background noise). Due to geometrical position of electrode and neurons, the amplitude of spike could be positively or negatively higher than the background noise.

The traditional technique based on this concept which finds a spike events from the extracellular signal if the signal crosses a user-specified single (or pair of) amplitude levels. The threshold can be set automatically from the signal's distribution statistics (median and standard deviation).

This is the simplest and most widely used technique. It only uses high-pass filtering for signal pre-processing. The performance of this technique deteriorates rapidly if the amplitude of background noise is almost similar to the spike amplitude (at low SNR).

Cepstrum of Bispectrum based Spike DetectionTechnique:

Cepstrum of Bispectrum based spike detection is a recently developed technique [1]. It is based on deconvolution theory where its average inverse filter information (both magnitude and phase) is estimated blindly from Cepstrum of Bispectrum [2] – a higher order statistical (HOS) measurement. The block diagram of this technique (*cob*) can be found in [1].

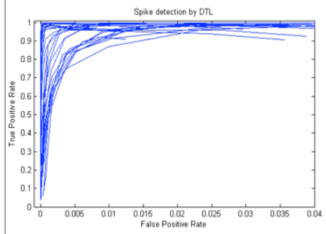
This technique has shown outstanding performance with simulated extracellular signal – it detects spike from 0dB signal (i.e., the average amplitude spikes and background noise are same). The key of this performance is that the *cob* looks signal's HOS distribution where it suppresses the background noise (Gaussian and/or i.i.d. signal) and highlights the spike events even at high noise levels.This method also needs amplitude thresholding at its final stage but due to application of HOS measurements it is not so difficult even for low SNR.

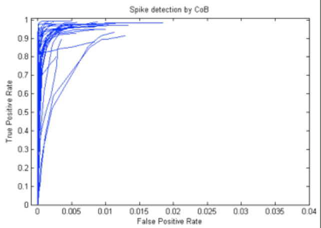
Performance Observations & Comparison

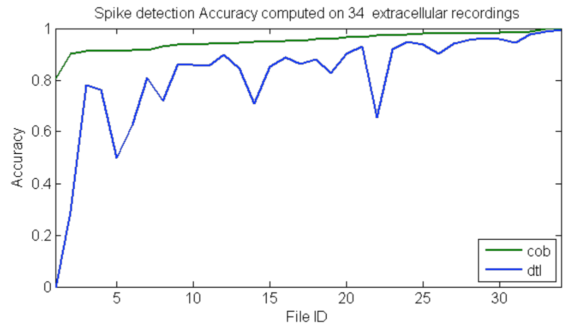
Both the traditional and advanced techniques have been applied to some real simultaneously recorded intra- & extra-cellular signals [4]. Two results are shown here: (a) the intracellular signal has high level of spikelet content (Fig. 3) and (b) the extracellular signal shows clear presence of spikes (Fig 4). The result after applying the algorithm has been shown at two stages: before and after final thresholding. In both signals the algorithm highlights spike events and suppresses noise.

Since the extracellular signal was recorded to observe the effect of the intracellular signal, the spikes detected by the different techniques were compared with the spikes from the intracellular signal. Spike detections matching the time of intracellular spikes are assumed true positive. Table 2 compares the techniques. The technique *cob* detects all spikes with fewer errors (false positive and false negative).

The performances show (a) with a good choice of threshold level *cob* can detect the highest number of spikes with highest precision – more than 99% of spikes are detected (at precision more than 99%) from signal at SNR up to 0dB. *cob* performs best even when spikes are very close (<1.0ms). (b) spike detection by *pln* deteriorates with level of noise, (c) detection of spike by *neo* is unreliable as it has the worst precision value.







Discussion and Conclusion

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