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 [1] at down to 0dB SNR (peak to peak signal to noise ratio) [2]. But with real extracellular signals *cob* sometimes does not perform as well as we expect from simulated signals. Here, we assess the *cob* technique using 34 real extracellular signals whose ground truth was estimated from concurrent intracellular signals from the a nearby target neuron. It is observed that the *cob* technique can detect target neuron 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 compared. We observe that *cob* almost always outperforms DTL in spike detection accuracy.

Problems of Finding Spikes in Extracellular Signal

Detecting and sorting of spikes from extracellular recordings is a challenging task as the electrode records its signal from a huge number of neighbouring neurons simultaneously, although only the spikes from few of neurons are relevant to the task under study and the rest of the neuron's signal is essentially noise.

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 extracellular signal are not always of significantly higher amplitude than the noise.

(c) Extracellular electrode/target neuron geometry varies from neuron to neuron resulting in different shapes of spike from different neurons.

(d) Different neurons' spikes may be superimposed.

(e) The overall shape of spikes from each neuron changes as a result of neural noise (sum of signals from surrounding distant neurons).

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

Spike Detection Algorithms - Traditional and Advanced Techniques

Standard Technique for Spike Detection:

It is generally assumed that the neurons of interest deliver signals (spikes) with a higher amplitude than the other neurons signals (considered to be background noise). Due to the geometrical configuration of the electrode and the neurons, the amplitude of each spike could be positively or negatively higher than the background noise.

The standard technique is based on this concept and finds spike events from the extracellular signal if the signal crosses a user-specified or double (+ve and/or –ve) amplitude level. The threshold can be set automatically from the signal's distribution statistics (using the median and standard deviation).

This is the simplest and most widely used technique. It requires only 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 (i.e. at low SNR).

Cepstrum of Bispectrum based Spike DetectionTechnique (*cob*):

Cepstrum of Bispectrum based spike detection is a recently developed technique [3, 2]. It is based on deconvolution theory where its average inverse filter information (both magnitude and phase) is estimated blindly from Cepstrum of Bispectrum [3] – a higher order statistical (HOS) measurement. The block diagram of this technique (*cob*) can be found in [2].

This technique has shown outstanding performance with simulated extracellular signals [1, 2] – it detects spikes even at 0dB SNR (i.e., the average spike peak amplitude and background noise peaks are same). The key to this performance is that the *cob* considers the signal's HOS distribution which suppresses background noise (Gaussian and/or i.i.d. signal) and highlights non-Gaussian events (spikes) even at high noise levels. This method also requires amplitude thresholding at its final stage but due to application of HOS measurements this has proven not to be too difficult even at low SNR.

Performance Observations & Comparison

The performance of both techniques (standard and *cob*) has been observed on 34 real extracellular signals recorded by the Buzsaki lab [4].

➤ The **ground truth for each extracellular signal** was computed from the intracellular signal simultaneously recorded from the same target neuron. Standard amplitude thresholding (median + 2 times standard deviation) technique was applied to the high-passed intracellular signal as it has high SNR & no overlapping spikes.

➤ With the **standard technique**, a high pass filter was applied to each extracellular signal before the application of double sided amplitude thresholding. The used threshold level was "median ± **η** times std" where **η** is 18 equispaced value from 0.25 to 4.5. When the signal crosses any threshold level it was compared with the ground truth (with 0.5ms tolerance). For ROC curve (Fig-1), the False Positive Rate (FPR) and True Positive Rate (TPR) were computed.

➤ With the **advanced technique (*cob*)**, the high-pass filtered extracellular signal was further processed using the *cob* based spike detection algorithm [2]. The amplitude of each detected spike train was normalized and thresholded by 4 linear spaced values from .01 to .04 and thereafter 19 linear spaced value from 0.05 to 0.95. The signal above threshold was compared with ground truth (again with 0.5ms tolerance). The FPR and TPR were computed for each signal for ROC curve (Fig-2).
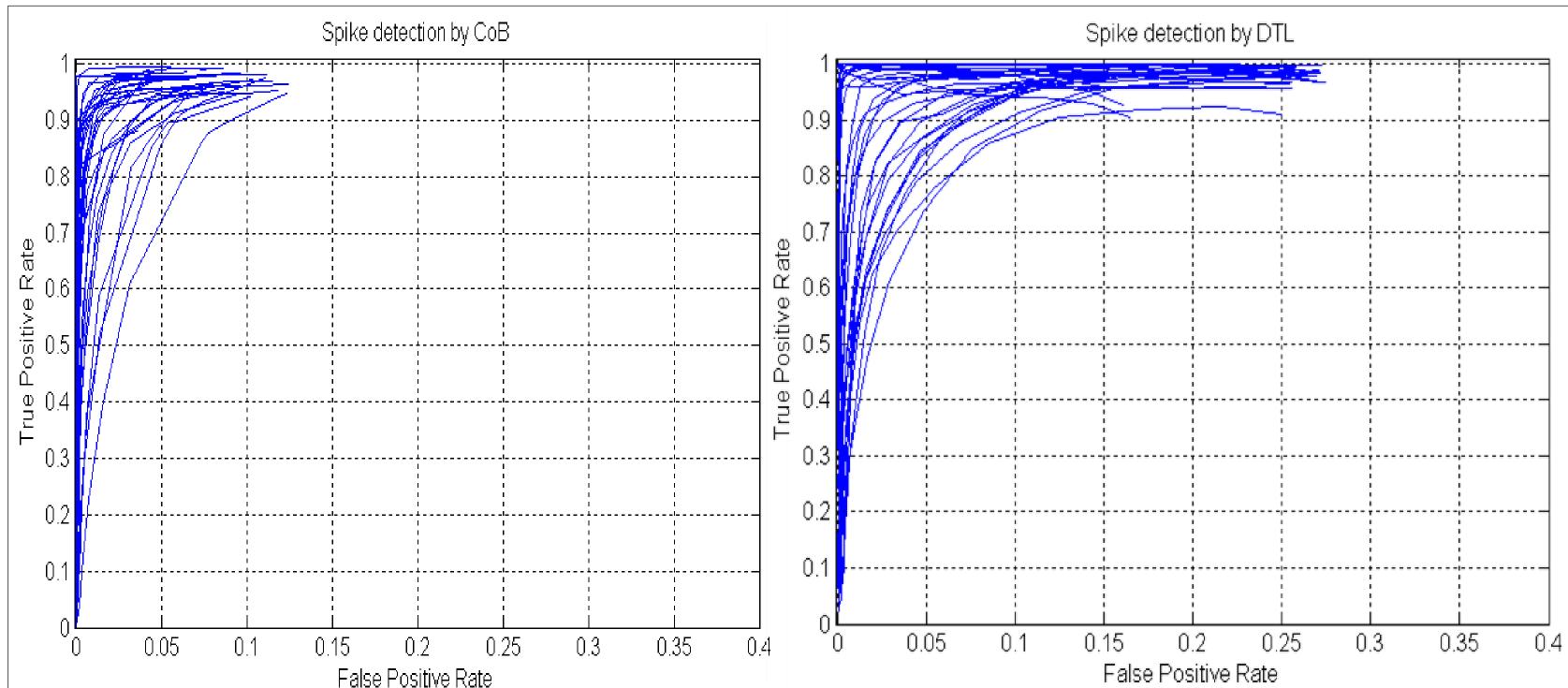

Fig. 1 ROC curve using *cob* technique for 34 recordings.

Fig. 2 ROC curve using Traditional double-sided amplitude thresholding technique for 34 recordings.

➤ To compare the accuracy of both techniques we consider 2 threshold levels where the average FPR of cob and DTL are almost equal (≈0.10). We applied the fixed threshold (for *cob*, 0.01, and **η** for DTL is 0.75) to all recordings and compute accuracy for comparison (Fig-3).

$$Accuracy = (TP+TN)/(TP+TN+FP+FN)$$
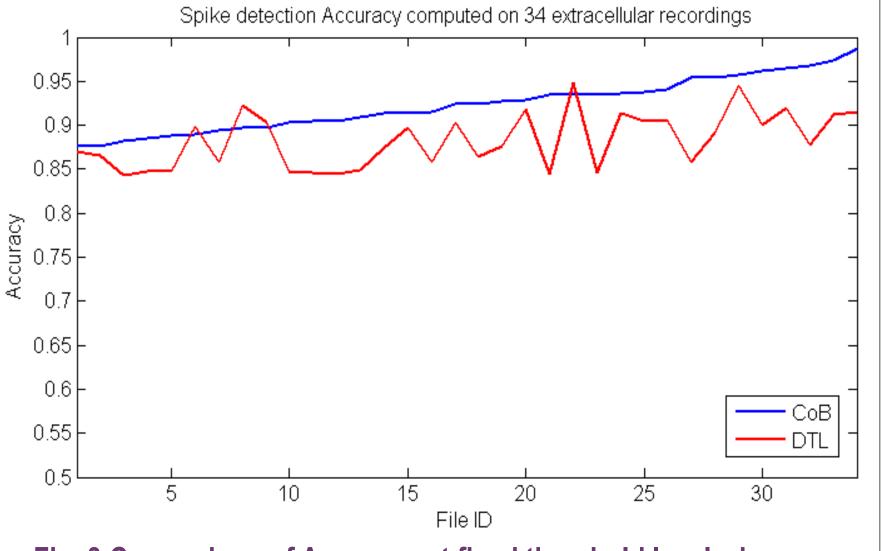

Fig. 3 Comparison of Accuracy at fixed threshold level where average FPR for cob and DTL are almost equal (ordered by increasing cob accuracy).

Discussion and Conclusion

Fig 1 concludes: the *cob* technique with the threshold value at 1% of normalized deconvolved signal can detect more than 95% of target neuron's spikes plus 7% to 10% additional non target neuron's spike (relative false positive). At higher threshold levels it is possible to detect 90% of target neuron's spikes with at least 5% relative false positive from 85% (30 out of 34) recordings.

Fig 2 concludes: with threshold = median ± std, the DTL technique detect more than 95% of true spike with 10% to 15% of relative false positive. With a higher threshold level 90% of target neuron's spikes can be detected with at least 5% relative false positive from 68% (24 out of 34) recordings.

The detection accuracy of both techniques (in Fig 3) at a certain relative false positive proves that the performance of cob is nearly always (30/34 times) better than the standard DTL technique.

Both these spike detection techniques are being deployed as services within the CARMEN Portal (see http://www.carmen.org.uk).

References

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