GDspike: An Accurate Spike Estimation Algorithm from Noisy Calcium Fluorescence Signals

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Introduction

- Spike Estimation: Obtaining the neuronal action potentials across time from Ca^{2+} fluorescence signals
- Electrode: Expensive set up, Harmful to mice, Hard for *in-vivo*
- Two-Photon Calcium Imaging: Activities of a population of neurons
- Challenges: Baseline fluorescence changes, Presence of random noise, Large time constant
- State-of-the-art algorithms: Vogelstein algorithm, STM Model and MLspike
- Classification: Model-based approaches and data-driven methods

Minimum phase Group Delay (GD)

- Fourier phase-based representation
- Direct computation:

$$\tau(\omega) = \frac{X_R(\omega)Y_R(\omega) + X_I(\omega)Y_I(\omega)}{|X(\omega)|^2}$$

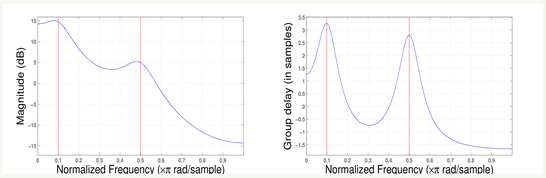

Figure 1 : High resolution and additive properties of the GD function [1]

- Fluorescence signal: Analogous to syllable STE in speech and Onset in Music (Fig. 2).

GD for spike estimation

1. Conversion to minimum phase: Smooth the symmetrized signal by raising it to a power of γ [2].
2. GD processing: Minimum-phase GD of the liftered signal gives spiking information
3. Post-processing: Triangulation at zero crossing positions to get the spike train

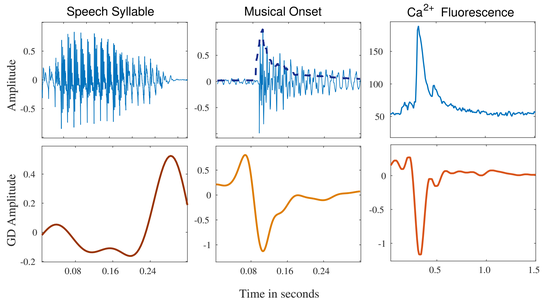

Figure 2 : Signal units comprising of onset, attack, and decay

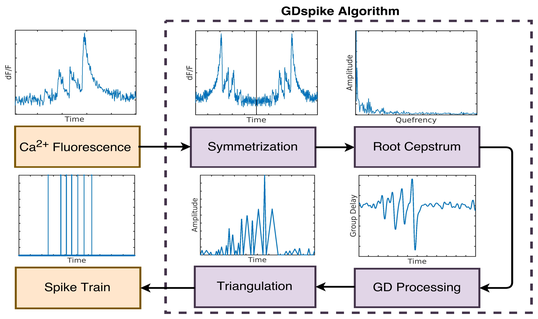

Figure 3 : Block schematic of GDspike algorithm

Important feature of GDspike

GDspike is a fast and non-model-based signal processing algorithm. Group delay representation acts as a denoising and peak-selective filter.

Dataset

- Consists of Ca^{2+} fluorescence signals and electrode action potentials which are simultaneously recorded from the mouse visual cortex neurons*.

Table 1 : Dataset used for evaluation

Set	#cells	Indicator	Samp. Rate (Hz)	# Spikes
1	9	GCaMP5k	50	2735
2	11	GCaMP6f	60	4536
3	9	GCaMP6s	60	2123
4	11	jRGECO1a	25	9080
5	10	jRCaMP1a	15	3624

Performance metrics

- F-measure: Temporal bin size $= 0.5sec$
- Area Under the ROC (AUC): Area enclosed by the TPR against the FPR
- Correlation: Calculated between every sample of spike train and the ground truth

[*] Open source dataset provided by Svoboda lab, at Janelia Research Campus. `http://crcns.org`

Results

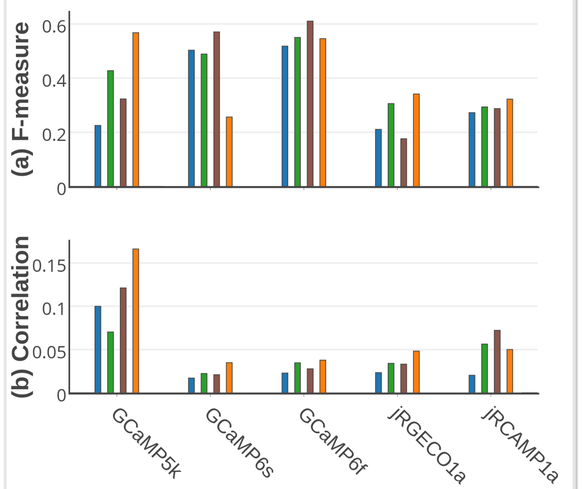

Figure 4 : (a) F-measure and (b) Correlation

- GDspike has the highest average F-measure (40%).
- AUC is comparable with state-of-the-art data-driven algorithm (STM).
- Better correlation value compared to Vogelstein.

[†] Source code, datasetwise-ROC and examples: `https://sites.google.com/site/groupdelayspike`.

Results

Table 2 : Average performance of different algorithms

Algo.	Recall	Precision	F-measure	correlation	AUC
Vogelstein	0.398	0.705	0.345	0.036	0.64
STM	0.469	0.752	0.394	0.055	**0.80**
MLspike	0.826	0.508	0.407	0.067	0.58
GDspike	0.648	0.520	**0.413**	0.043	**0.79**

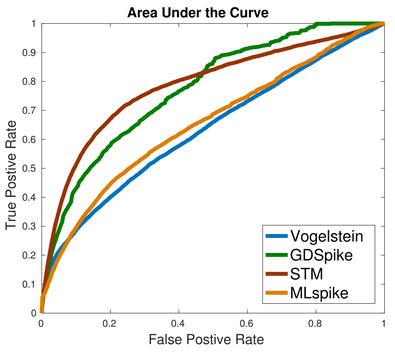

Figure 5 : ROC averaged across the datasets

Conclusion

- A non-model-based signal processing algorithm is proposed†.
- An improvement in F-measure and comparable AUC with respect to the baseline algorithms are observed.

References

[1] Jilt Sebastian, Manoj Kumar, and Hema A Murthy. An analysis of the high resolution property of group delay function with applications to audio signal processing. *Speech Communication*, pages :42–53, Feb. 2016.

[2] T Nagarajan, V K Prasad, and Hema A Murthy. Minimum phase signal derived from the root cepstrum. *IEE Electronics Letters*, Vol.39 pages:941–942, June 2003.

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