Modeling and Analysis of Electrophysiological Activity Using Matrix Pencil Method

Ecole doctorale Sciences Pour l'Ingénieur

Z. MIZOURI[1], K. EL KHAMLICHI DRISSI[1], L. MONCONDUIT[2], C. PASQUIER[1], B. SION[2] and F. GABRIELLI[2]

[1] Pascal Institute, CNRS, SIGMA Clermont, Clermont-Auvergne University

[2] NEURO-DOL Laboratory, INSERM, Clermont-Auvergne University

Introduction

This work is achieved in collaboration between two interdisciplinary laboratories, Neurol-Dol for health sciences and Pascal Institute for engineering sciences. The subject is to develop a high resolution signal processing tool in order to have a better understanding of pain message and its propagation from the peripheral to the central nervous system.

Electro-stimulation is one of the most used techniques in analyzing neural activity. Recorded signal are always contaminated by the appearance of stimulus artifact. In order to eliminate this useless information and to focus only on neural response, we propose to use a high resolution Matrix Pencil Method (MPM).

The choice of Matrix Pencil Method is based on three criteria: allowing a lossless data compression, providing robustness to measurement noises and the ability to reconstruct truncated signal (useful in the case of stimulus artifact saturation).

Method

✓ **Diagram of experimental procedure**

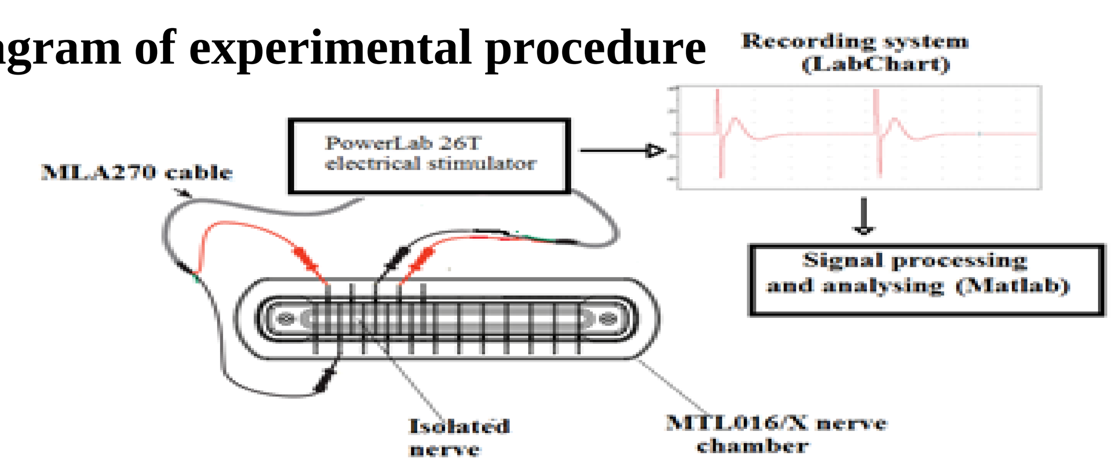

Fig.1 Diagram of experimental procedure

Our data is composed of signals recorded in vitro on the sciatic nerve of a rat, stimulations ranged from 20 to 400 mV (20mV step) with a duration of 200µs and 500 µs, and were repeated 3 times (represented by Test 1 to 3 in result figures).

✓ **Matrix Pencil Method:**

In our case, we use Matrix Pencil Method for measured signal identification. The signal *y(t)* can be written in the following form:

$$y(t) = x(t) + w(t) = \sum_{j=1}^{M} R_j e^{s_j t} + w(t)$$

Matrix Pencil is based on the identification of the number of M significant poles, the complex value of each poles s_j and the complex value of each corresponding amplitude R_j. *w(t)* represents the measurement noise.

✓ **Stimulus artifact removal:**

Our method propose to decompose stimulus artifact into two symmetrical [A] an [B] parts (Fig. 2). In the case where stimulus artifact and response are clearly separated (Fig. 3). , the duration between artifact peaks allows us to ascertain the duration of [A] an [B] parts.

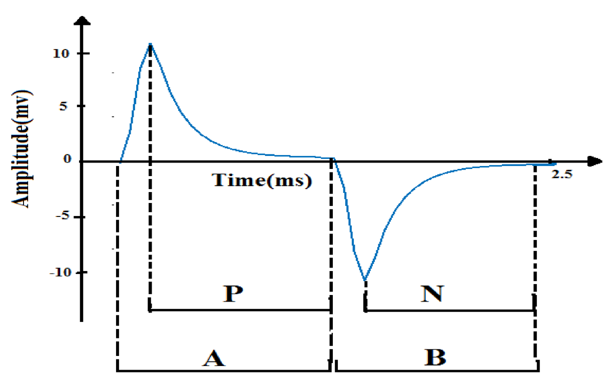

Fig.2 Stimulus artifact wave form

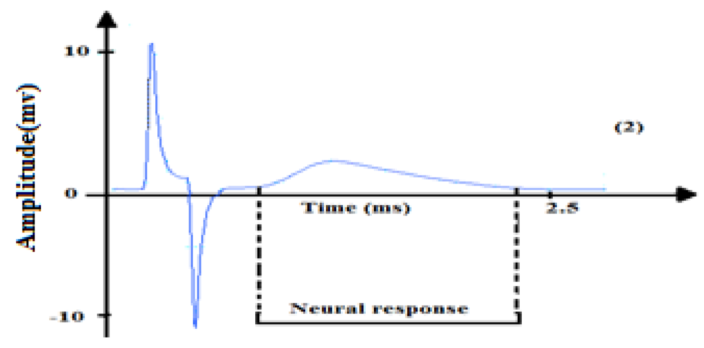

Fig.3 Example of signal with neural response

Under the hypothesis that [A] and [B] are symmetrical, the proposed method reconstructed the exponential part (N) of [B] from the corresponding exponential decay part (P) of [A] and prolong it with the series of M damped exponentials.

In the case of stimulus artifact saturation, it corresponds to input signal overloaded. Only late part of the exponential decay [P] is treated.

In this case, we reconstructed the late part of decay exponential [a2] from the portion [a1] (Fig. 4).

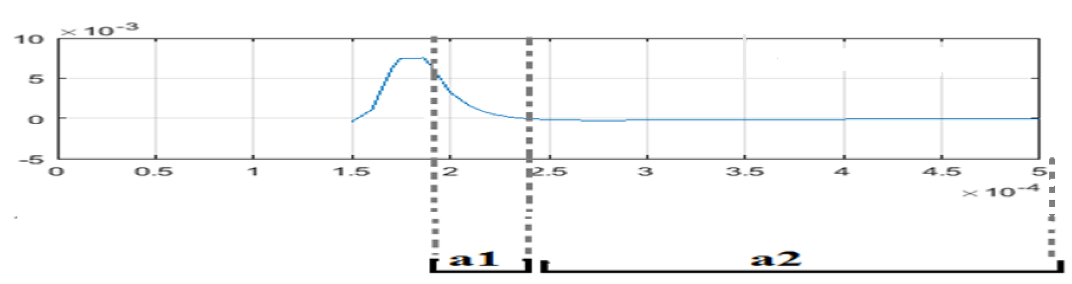

Fig.4 Example of truncated signal

Hypothesis validation and reconstruction quality was assessed with normalized mean square error (NRMSE) .

Results

✓ **Symmetry hypothesis validation**

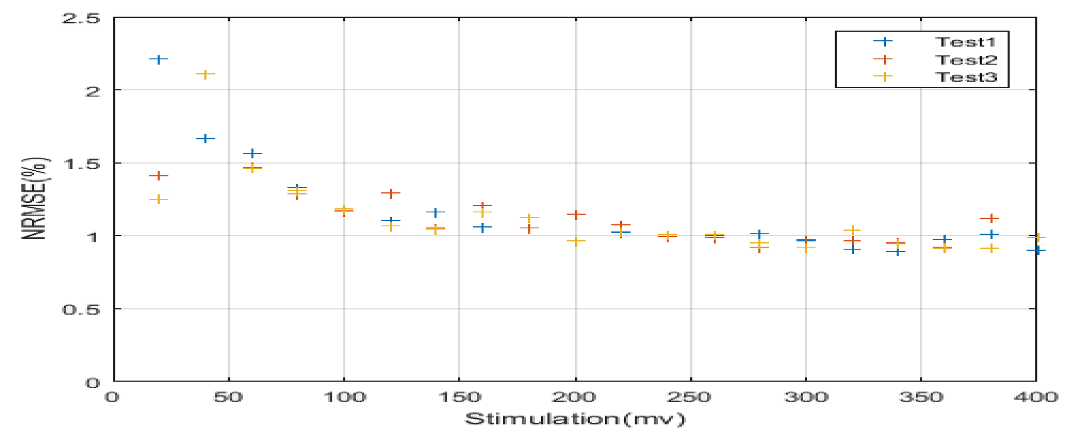

Fig.5 Difference between [A] and [-B] part of artifact, pulse width 200µs, pulse amplitude from 20 to 400mV (increment of 20mV), (Experience is repeated 3 times for the same experimental conditions: Tests 1 to 3)

An NRMSE with a mean of 1,3% and a standard deviation of 0,5% was obtained between [A] and [-B] for the range of electrical stimulations. This result validate our hypothesis of symmetry.

✓ **Quality of reconstruction**

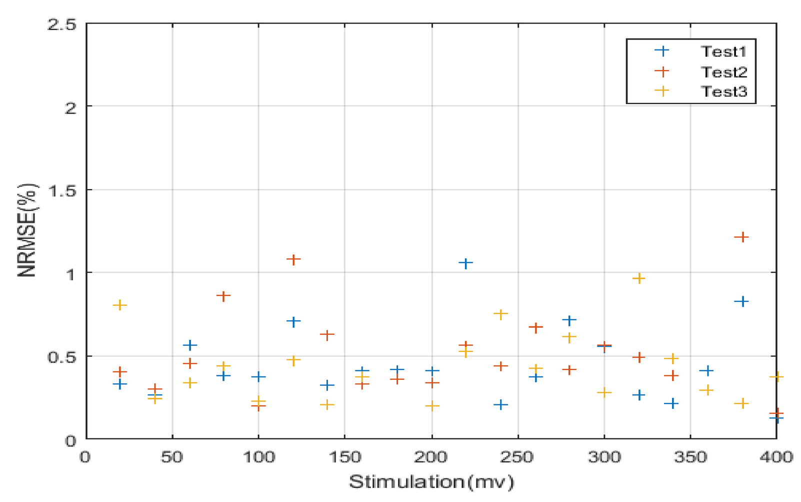

Fig.6 Reconstruction error of [A], pulse width 200µs

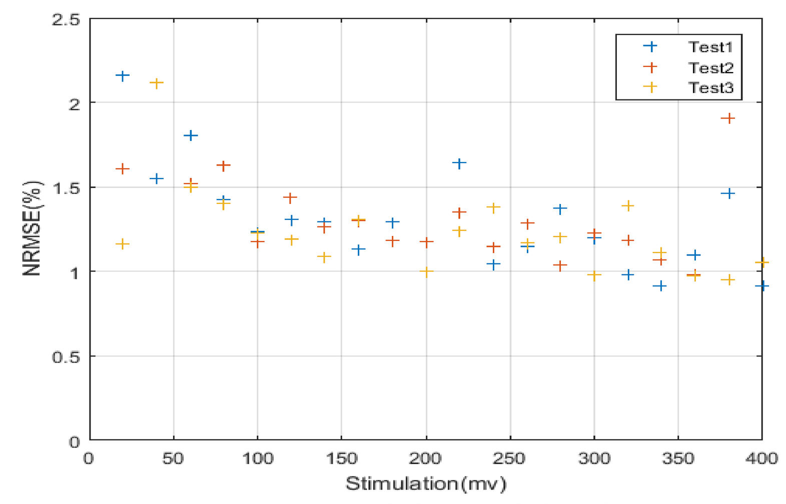

Fig.7 Reconstruction error of [B] from [A], pulse width 200µs

With only three significant poles, an NRMSE with a mean of 0,47% and a standard deviation of 0,25% was obtained for the reconstruction of [A]. For the reconstruction of [B] from [A], an NRMSE with a mean of 1,45% and a standard deviation of 0,54% was obtained (Fig.6 & Fig.7).

✓ **Truncated signal**

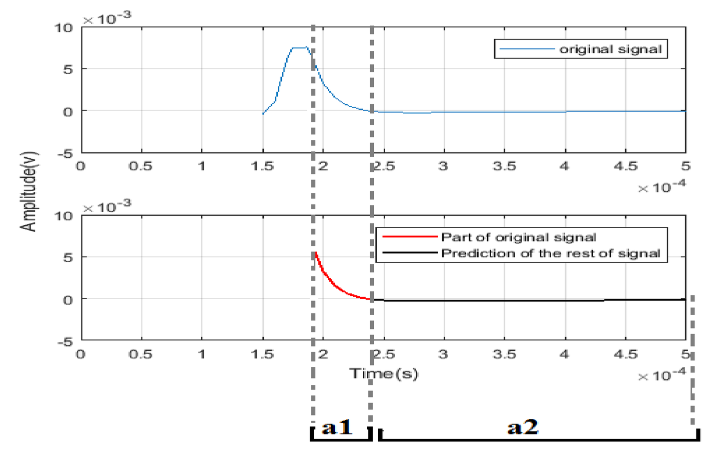

Fig.8 Truncated signal reconstruction, pulse width 500µs, pulse amplitude 400mV

The Matrix Pencil Method is already efficient in identifying truncated signals (Fig.8).

✓ **Stimulus artifact removal**

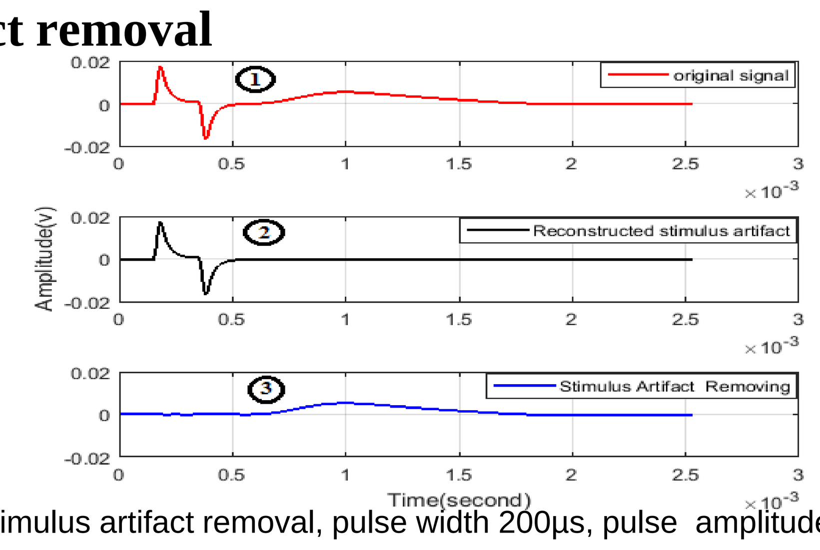

Fig.9 Stimulus artifact removal, pulse width 200µs, pulse amplitude 400 mv

Those results show clearly the potential of our technique in stimulus artifact removal.

Conclusions

- Identification mean error by using Matrix Pencil Method is less than 1,5%.
- Matrix Pencil predict late part of the signal based on few samples.
- Stimulus artifact removal is achieved successfully.

In term of perspectives, we suggest to extend the prediction of late part of artifact in the case when the stimulus artifact is contaminated by the neural response.

Later on, we will classify neural responses in different clusters.

Bibliography

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