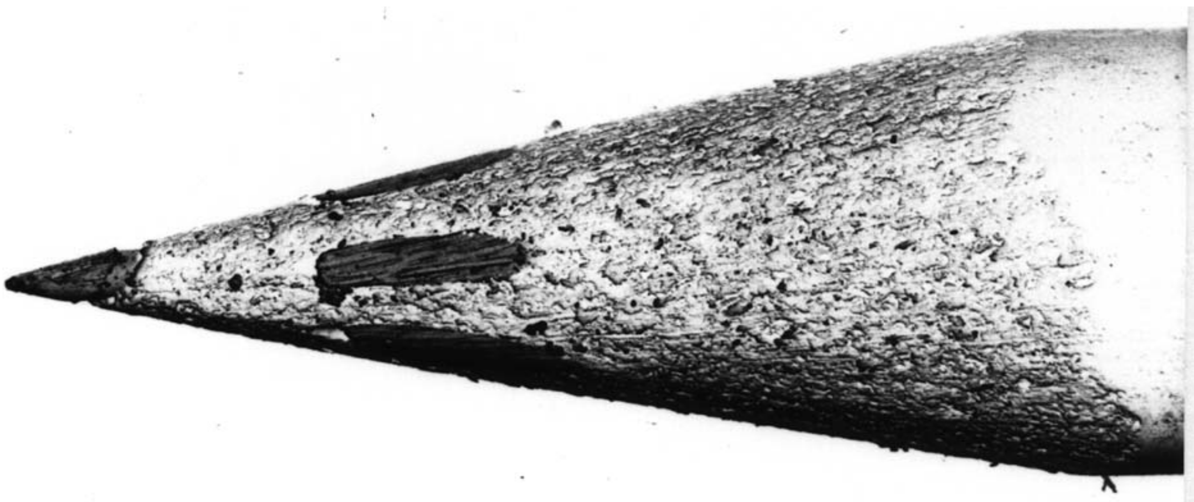
Heptode

(7-cores Multifiber Electrode)

Datasheet



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Dimensions of the Heptode

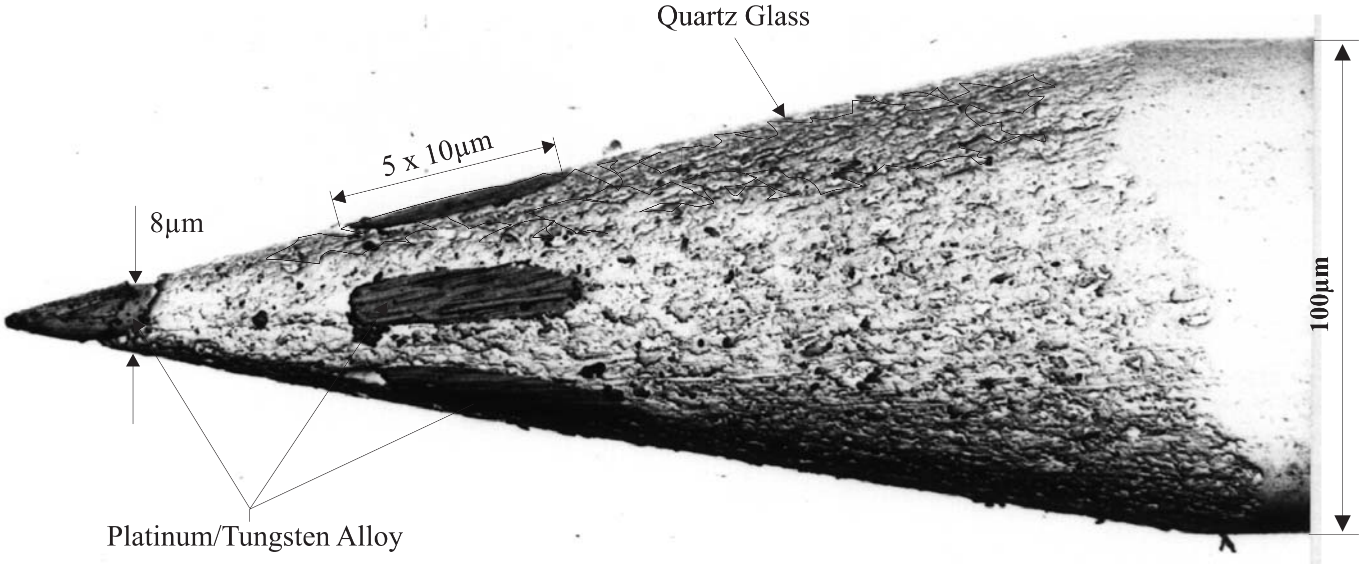

Figure 1: Scanning Electron Microscope Photo of the Heptode Tip

The paper presented at the 18th Annual International Conference of the IEEE Engineering in Medicine and Biology Society, October 31-November 3, 1996; Amsterdam, The Netherland

CLASSIFYING NEURONAL SPIKES FROM MULTIUNIT RECORDING BY USING A MULTISITE ELECTRODE

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Abstract - A method of classifying neuronal spikes was proposed and achieved by multiunit recording using a multisite electrode and by considering spatial damping vectors. The method consists of three procedures, i.e., separation of overlapping spikes, treatment of burst spikes, and clustering by a multi-dimensional statistical test. The first and second procedures clarify the border between clusters and the last procedure validates the classification statistically. By using this method, multiple neuronal spikes were automatically classified and the waveforms of the spikes in each class were well superimposed. We concluded that this method is superior to other methods of classifying neuronal spikes.

I. INTRODUCTION

A major problem in extracellular microelectrode recording from cell-dense regions of the brain (e.g., hippocampal pyramidal cell layer) is the separation of spikes (action potentials) originating from different neurons. Among various methods used to resolve this problem, the stereotrode method [1] appears most promising both in theory and in practice. This method is based on the fact that the ratio of two spike amplitudes detected at two adjacent electrodes is constant for a given neuron but different for different neurons. Peak amplitude is, however, unstable at low signal-noise (S/N) ratios or low sampling frequency.

We proposed a method of classifying neuronal spikes by multiunit recording using a multisite electrode and by considering spatial damping vectors[2]. The damping vector is stable at low sampling frequency and low S/N ratios. However, the method was not refined yet to be able to decompose partially superimposed spikes. Here we modify the method to automatically decompose spikes which are noisy, bursting and overlapping with each other.

II. METHODS

A. Principle.

Disregarding the action potentials generated on the axons and dendrites of the neuron and assuming that the electrophysiological environments inside and outside the neuron are regular, we can consider that the same spike waveform is observed at the same position where the neuron exists relative to an extracellular microelectrode.

The k-th spike generated by a neuron is described as

$$v_{k,n}(t+T_k) = h(t,r_n) \otimes w(t+T_k), \quad (1)$$

where $h(t,r_n)$ is the impulse response function of the damping factor (i.e., the volume conduction from the neuron to the n-th electrode site), t indicates the local time, T_l is the global time when the k-th spike occurs, and $\otimes$ is the convolution operator. Focusing on the attenuation effect of the spatial damping factor, the estimated value of $h(t,r_n)$ must be the covariance between $w(t+T_k)$ and $v_{k,n}(t+T_k)$ (see reference [2] for details).

The spatial damping factors from N sites of the multisite electrode are evaluated and vectorized as

$$\left(h(t,r_1), h(t,r_2), \cdots, h(t,r_N)\right). \quad (2)$$

Since this spatial damping vector depends on the position of the neuron, the clusters of vectors correspond to different neurons. Thus, the spatial damping vectors are clustered by a hierarchical clustering method incorporating the multi-dimensional statistical test with the null hypothesis "the distributions of two clusters are identical."

B. Separation of overlapping spikes.

Since each observed spike has similar waveform to that shown in figure 1, the positive deflections of K preceding spikes cause errors in estimating $h(t,r_n)$ of $(K+1)$-th spike. To avoid the errors, the components of the preceding spikes are subtracted from the observed waveform $f_n(t)$ as follows:

$$f_n(t) - \sum_{k=1}^{K} \hat{h}(t,r_n) \cdot w(t+\hat{T}_k), \quad (3)$$

where $\hat{h}(t,r_n)$ and $\hat{T}_k$ are the estimated values of $h(t,r_n)$ and T_k, respectively.

C. Treatment of burst spikes.

When a neuron is activated in bursting mode, the previous spike in a spike burst is larger than the following spike. Since the first spike of a spike burst must not be affected by the firing mode, the burst spikes can be represented by the first spike in the spike burst.

The procedure for detection of a spike burst is as follows: (1) detect a spike pair having an interspike interval of 2 to 13 ms, (2) if the damping vectors of the paired spikes have a higher correlation value than 0.95 and a norm ratio (latter/former) between 0.8 and 1.1, the paired spikes are included in the same spike burst, (3) repeat steps (1) and (2). The constant values in this procedure are determined arbitrarily.

III. RESULTS

A. Data acquisition and the number of clusters detected.

A quartz-coated electrode with 6 platinum/tungsten (90/10) cores as shown in figure 2 was used as the multisite electrode, i.e., N=6, and was placed in the hippocampal (CA1) pyramidal cell layer of urethane-anesthetized rats. The reference electrode was a stainless-steel button of 1mm diameter on the cerebellar surface. The signals from 6 channels were amplified, bandpass filtered at 500Hz-10kHz, and digitized at 20-100 kHz/ch using a set of 12 bit AD converters.

As a result, 1432 spikes were detected from a 25 s recording and were classified into 14 clusters, each of which contained more than 10 spikes. The spikes in each class were well superimposed. Here, the rejection region of the statistical test was less than 2%.

B. Distribution of damping vectors.

Since a technique to graphically represent 6-channel damping vectors is presently unavailable, only two channel data will be presented here to evaluate the modifications of the proposed method. Figure 3 shows the result of projecting damping vectors to explain the effect of canceling preceding spikes ((a) and (b)) and canceling burst spikes ((c) and (d)).

IV. DISCUSSION

A. Spike detection with canceling of preceding spikes.

In our previous study[2] using a covariance with the template as a damping factor, the damping vector was shown to be stable at low sampling frequency and low S/N ratios. However, cluster A in figure 3(a) had a negative value of $h(t, r_3)$. Since the neuronal spikes were observed by the extracellular recording, the negative value was unlikely. Superimposing spikes of cluster A revealed that the negative value was caused by the positive deflection of the preceding spikes which appeared regularly before the spikes in cluster A (see figure 4(a)).

To avoid this situation, the preceding spikes were canceled in advance (see figure 4(b)). Using the cancellation procedure, clusters A and B merged into cluster C. Since the cancellation procedure is simple, this modification is useful.

B. Treatment of burst spikes.

It is well known that spikes in a burst have decreasing amplitudes. Consequently, small spikes in bursts tended to be included in clusters of small nonbursting spikes. Here spike bursts were detected and processed with the exceptional procedure so that the border between two clusters, e.g., regions D and E, became clear as regions F and G. Thus, the above problem was solved.

C. Clustering using the multi-dimensional statistical test.

In figure 3(d), it is impossible to distinguish the clusters H and I by referring to the values on the X-axis because the marginal distributions of these clusters overlap along the X-axis. Thus, the joint distribution on the X-Y plane must be employed for clustering. Here, we used a hierarchical clustering method incorporating the multi-dimensional statistical test.

V. CONCLUSIONS

By using the proposed method, multiple neuronal spikes are automatically classified and the waveforms of the spikes in each class were well superimposed. We conclude that this method is superior to other methods of classifying neuronal spikes.

REFERENCES

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[2] H. Kaneko, S. Suzuki and J. Okada, "A method classifying neuronal spikes from multiunit recording by using a 7-core electrode," IEEE EMBS 17th annual conference CD-ROM, 1995.

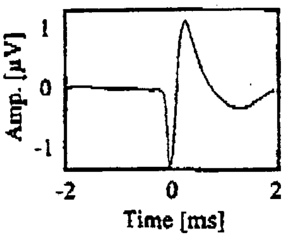

Fig. 1 Template.

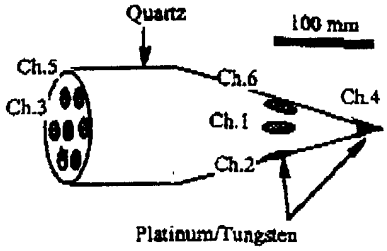

Fig. 2 A multisite electrode.

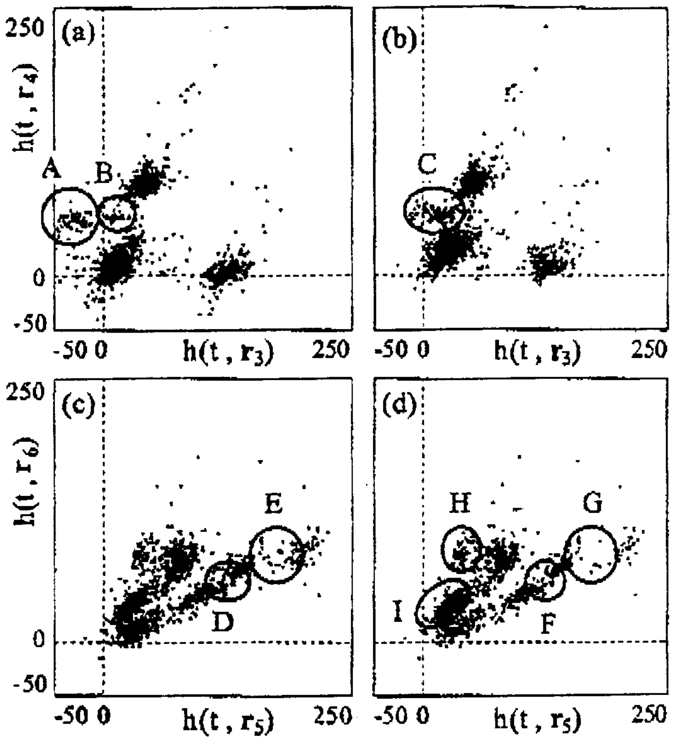

Fig. 3 Plots of the damping vectors. Spike detection (a) without canceling of preceding spikes, (b) and (c) with canceling of preceding spikes, and (d) with canceling of preceding spikes and burst spikes.

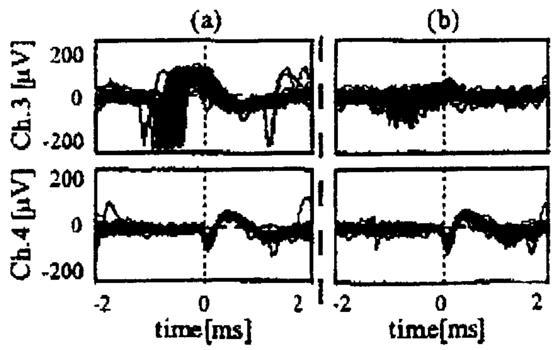

Fig. 4 Superimposed spikes. (a) Cluster A in Fig. 3(a). (b) Cluster C in Fig. 3(b) (preceding spikes were subtracted).