Implementation of extracellular neural recording system and study of evoked signal preprocessing method

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Abstract: - A multichannel recording system of extracellular cortex is utilized to acquire the neural signal of primary somatosensory cortex in rats. The extracellular neural recording system includes mainly the acquisition sub-system, the monitoring sub-system and the analyzing sub-system. We use the microwire array electrode to record different signal of three types; those are from on air, from S1HL without stimulation and from S1HL with stimulation by scratching the claw of the left hind leg using a brush. A signal processing system is applied to deal with the saved data. Through the method of spectral subtraction, we can reduce the influence of noise. Beside, nonlinear energy operator algorithm is employed to detect the timestamp of evoked potential by external stimuli. The signals are according to the time interval between preceding and following of timestamp to separate apart into every section. Each section can proceed to extract the features from every small segment of the signals and classify evoked potential segments that own similar features to the same group in the future. Finally, the information of the monitor system are apply to verify the accuracy of spike detection that the information comprises the action of external stimulus, the waveform of neural signal and the voice of speaker, simultaneously. Through the result of experiments, the developed recording system is suitable for intracortical signals recording; the proposed method is feasible and effective for noise reduction and spike detection of extracellular evoked potentials.

Key-Words: - Microwire array electrode, Extracellular recording, Somatosensory evoked potential, Brain machine interface, Moving average, Spectral subtraction, Nonlinear energy operator

1 Introduction

Evoked potential is an electrical potential recorded from a human or animal following presentation of an external stimulus, is distinct from spontaneous potentials. The common evoked potential includes visual evoked potentials (VEP), auditory evoked potentials (AEP), somatosensory evoked potentials (SEP) and motor evoked potentials (MEP). SEPs are the most widely used in clinical and research applications, and form of evoked response testing. SEPs are mostly generated in anaesthetized rats. It is well know that anaesthetic drugs strongly modify responses to noxious stimulation and thus modify the SEP signal. These specific SEP waveforms do not necessarily represent physiological functioning in awake rats and as a consequence, can not be uses as baseline data for investigating anti-nociceptive efficacy of analgesic drugs [1].

Invasive Brain-machine interface (BMI) systems are based on the recording from the ensembles of single brain cell or from the activity of multiple neurons. Such systems provide neural signals of the best quality and have the potential to improve the accuracy of measurement. In extracellular recordings, an electrode placed in the cortex usually records spike activity from a number of neurons proximal to the electrode. When measured extracellularly, the extracellular potential raises and action potential (also called a spike) normally with 50-500μV in amplitude can be observed. The relevant frequencies of these action potentials range from 100Hz to about 7 KHz [2]. The measurements involve voltages at very low levels, with high source impedances and superimposed high level interference signals and noise. The signals need to be amplified to make them compatible with devices such as displays, recorders, or A/D converters for computerized equipment.

The meaning of the spike represents localized high frequency and increase in instantaneous energy in signal processing techniques. The quantitative descriptions of the amplitude and spectrum of spikes vary from signal to signal,

subject to subject; it even varies from time to time for the same subject. This is precisely why detection and pathological implications of spikes become difficult. As the spike base width increases, energy is concentrated more in the low-frequency band where the energy of the background signal is also located and detection becomes more difficult in the frequency domain. In the analysis of biomedical signals, spikes are important for diagnosis. The spikes characterize epileptic seizures in EEG. Spike detection is important in many pathological cases as well as in the measurement of R–R intervals in an ECG [3]. In this paper the spikes describe evoked potentials of somatosensory cortex by an external stimulus.

The neural signals of extracellular recording consist of action potentials from several neurons near the electrode site, and background noise. Since information of the nervous system is encoded in the form of firing frequency or firing time [4]. The detection of the neural spike is the first procedure in the explication of neuronal signals. A few studies on neural spike detection have appeared in the literature. In most cases, major efforts have been made to optimize experiments so that the recorded waveforms are of sufficient quality to enable reliable detection by simple traditional methods. But, many situations are often encountered where the signal-to-noise ratio (SNR) of the recording is as poor as to prohibit neural spike detection using simple threshold, and in some cases, such as the recording from a long-term implanted electrode, precise experimental control cannot be achieved [5].

In the paper, we use a multichannel electrode of microwire to acquire the neural signal of primary somatosensory cortex (S1) in rats. The recorded data includes the environmental signal captured on air, the neural signal of S1 without stimulus, and the evoked potential of S1 with a variety of stimulants. A signal processing system applied to deal with the saved data. Through the reprocessing of spectral subtraction, we can reduce the influence of noise and increase the signal-to-noise ratio. Then a nonlinear energy operator (NEO) is employed to detect the time of spike from neural evoked potentials by external stimuli. And based on these detected points, we can segment the neural signals according to the length of further analytic need. Finally, the information of the monitor system is applied to estimate the performance of proposed algorithm in the study.

2 Material and Methods

A multichannel recording system is prepared in order to achieve the goal of studying. The functions of recording system comprises mainly the capture of neural signal, the store of several data, the supervision of experimental procedure and the analysis of digital signal. First, we fabricate a microwire array electrode and implant into the S1HL to record the neuronal signal by stimulates the hindlimb. Besides, we also record the signals of microelectrode on air and the signals of S1HL without stimulus, these signals are useful for reduction of noise signal. Then the acquired signals are transformed into digital signal for further processing. Next, the spectral subtraction is applied to suppress the noise. After that, the NEO is utilized to detect exactly the response time of evoked potential by external stimulation. Finally the extracellular neural signals are separated into each section according to the response time.

2.1 Microwire array electrode fabrication

A six-channel microwire array electrode for a multi-site is described to illustrate the fabrication procedure. Electrochemical impedance spectroscopy is used to measure the impedance and the phase between the electrode and the electrolyte, and then to obtain a suitable microelectrode for recording cortical neural activity. The microwire array electrode is composed of 50 μm-diam Teflon insulated tungsten microwires, a printed circuit board (PCB) pattern, a flexible flat cable (FFC) and connector and viscose of epoxy A+B that is proposed herein. The PCB pattern of eight-channel is used to implement the fabricative process. A six-channel microwire array electrode is fabricated to cooperate with the neural signal acquisition recording system and is applied to measure the extracellular cortical signal. These main steps of a microelectrode fabrication include connecting PCB pattern, arraying and soldering microwires and packaging the microelectrode. Before an electrode fabrication can work, the layout and the sculpturing of the PCB must be completed, and the microwires straightened. The PCB after finish procedure of design and sculpture becomes PCB pattern. Taking a six-channel microelectrode as an example: the first six copper dots on the top layer of the PCB pattern are used soldered to the six microwires. A

stainless-steel wire is soldered to the ninth copper dot. This wire is the reference end of the signal capture circuit. The tenth copper dot of the PCB top layer is connected to the ground end of the signal capture circuit and the body of the animal. In Fig.1, a six-channel microwire array electrode is finished for use in this study.

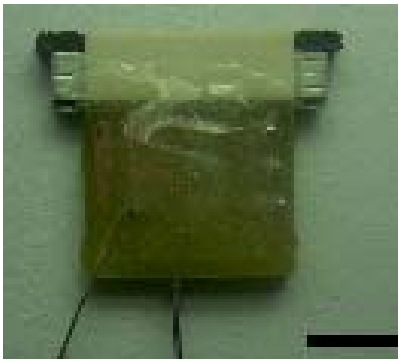


Fig.1 Assembly of six-channel microwire array electrode for multi-site recording. Calibration bars of 5 mm.

2.2 Extracellular recording system implementation

In this study, we have realized a multichannel neural recording system. The extracellular neural recording system includes the signal acquisition sub-system, the condition monitoring sub-system and the signal analyzing sub-system. The overall system architecture is shown in Fig.2.

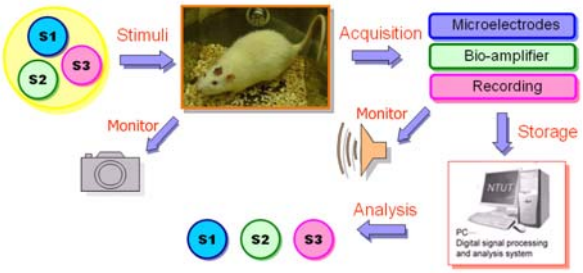


Fig.2 The overall architecture for multichannel neural signal recording system.

2.2.1 Acquisition and monitor system design

The six-channel acquisition sub-system is used to record extracellular cortical evoked potentials in the S1HL. Since the amplitude of the cortical neural signal can be as low as tens of μVrms, it must be appropriately amplified and filtered before further processing. Then, the boosted signal can be transmitted away from the subject. The typical extracellular acquisition system architecture is shown in Fig.3.

The acquisition system takes three electrodes and ground free mode for recording extracellular signal of somatosensory cortex. The three electrodes of every channel connect the subject to a low noise preamplifier stage. After preliminary removing dc and wider bandwidth interferences by the passive band-pass filter, the signal is connected to a variable gain post-amplifier through adjustable active low-pass and high-pass filters stage which provides the desired biosignal to researcher. The sifted analogy signal transmits to A/D converter, then processing the further data analytical work. The pre-amplifier (TI INA2128) provides nearly 20-fold gain, a large CMRR (above 100dB) and low-noise voltage density by a differential amplifier stage. The variable gain of post-amplifier (AD OP27) is 32, 64, 128, 256, 512 and 1024 times separately. The filter circuit (TI TL074) is a bandpass filter with whole frequency range around 0.1 Hz – 10 KHz. The total gain of active filter is set to about 11.4-fold. NI-DAQ card (NI PCI-6250) is used to digitize the acquired signal using a sampling rate of 30 KHz for further processing and analyzing. Moreover, Lab VIEW is a good tool to design a GUI program for multichannel recording the neural signal into personal computer.

The monitoring sub-system will record the timing of external stimuli and actions in rat by a video recording device. At the same time, an audio speaker is used to help us determine the exact position of implanted microelectrode in S1HL in order to obtain a better quality of cortical signal. Then, can meantime deliver the signal to the oscilloscope for the observation of neural waveform.

2.2.2 Analysis and processing system development

In the study, the functions of signal analysis sub-system include Fast Fourier Transfer (FFT), Joint time frequency analysis (JTFA), Wavelet analysis (WT), Auto-correlation, Cross-correlation and Nonlinear Energy Operator (NEO). We use Lab VIEW and MATLAB to develop analytic programs. The functions of feature extraction and cluster can be expanded according to demand of experiment in the future. The frame of neural signal analysis and processing is shown in Fig.4.

FFT can characterize frequency property to a section of signals in one time interval. In the biosignal analysis, we sometimes need to find out the frequency distribution of a section of signals in a short time interval. To analyze the relation of frequency distribution to time in the short time interval is called JTFA. The WT can provide different decomposition of the capture biosignals in time domain ranged in various frequency resolutions. Auto-correlation is used to measure self-similarity

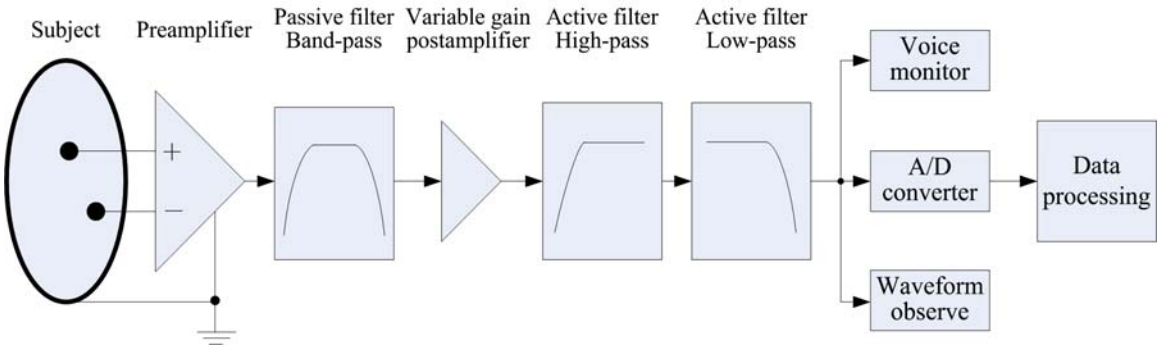


Fig.3 A typical designs of the various stages for extracellular acquisition system.

of one function itself and the cross correlation is use to measure cross-similarity of two different functions. The spectral subtraction is applied to reduce the noise from environment, equipment and other bio-signals. Through the processing of noise reduction, send the signals to next process of spike detection, the NEO is applied to detect the time of response from external stimuli. Then the signals are according to the time interval between preceding and following of response time to separate apart into every section.

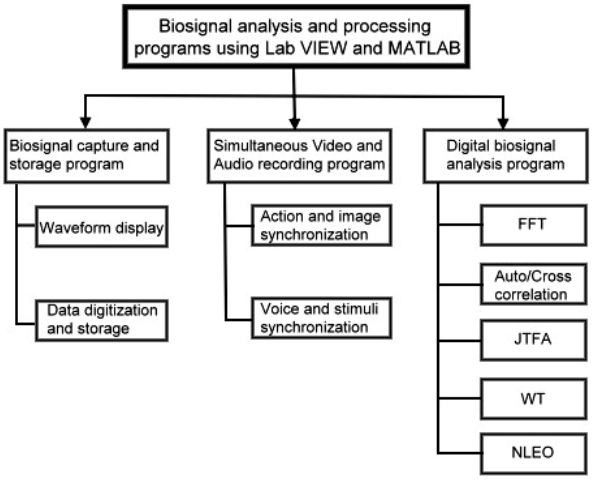


Fig.4 The frame of neural signal analysis and processing.

2.3 Signal preprocessing method

In the experiments, we use the spectral subtraction and the NEO algorithm as a preprocessing step of neural signal analysis. The spectral subtraction is employed to reduce the noise the NEO is utilized to detect the evoked spike. The procedures and techniques of operation are introduced separately below.

2.3.1Spectral subtraction

The extracellular neural signal consists of five components mainly; among them include the desired biopotential, undesired biopotentials, a power line interference signal of 60 Hz (50 Hz in some countries) and its harmonics, interference signals generated by the tissue and electrode interface, and environmental noise. In actual neural signals, we can consider as noises if they appeared on air, in cortex without stimulation and in cortex with stimulation. Then the noises can be eliminated by spectral subtraction. A diagram of the noise reduction is shown in Fig.5.

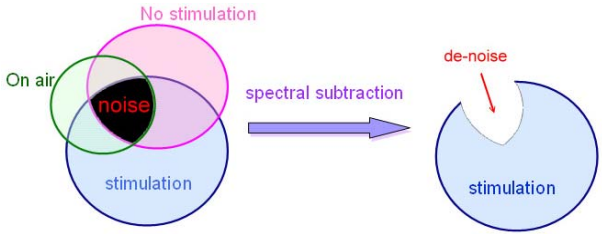


Fig.5 A diagram is to show what noises need to be eliminated.

In speech analyses, the spectral subtraction is a good way to suppress the noise. It is used to estimate the magnitude frequency spectrum of the underlying clean speech by subtracting the noise magnitude spectrum from the noisy speech spectrum. Therefore, we use this method to reduce the noise of neural signal before further analysis. The following steps for the noise reduction of neural signal: (1) transforming the raw signal of on air, without stimulus and stimulus in cortex to the spectrum by the FFT, (2) calculating the mean value of on air and without stimulus signal by the simple moving average, (3) deciding the target of spectral subtraction by the averaged value of on air, (4) processing the noise reduction of stimulated signal according to the averaged magnitude of without stimulus, (5) converting the processed signal of stimulation by the inverse FFT. This procedure is designed and implemented to effectively decrease the noise of extracellular neural signal result from environment and instrumentation.

2.3.2Nonlinear energy operator

The NEO is already used to estimate the instantaneous frequency and amplitude of a sinusoid [6]. The applications of the NEO for biomedical signal processing have been discussed in some literatures. A new interpretation of NEO and extend its use in stochastic signals and real EEGs [3]. The NEO can be used to quantify a type of energy that is based on amplitude as well as frequency and segment EEGs [7]. The use of nonlinear energy operator enables the detection of an action potential, even when the SNR is so poor that a typical amplitude thresholding method cannot be applied from an abdominal ganglion of sea-slug [8]. A smoothed nonlinear energy operator is applied to the contaminated EEG, which significantly emphasized the ECG artifacts compared with the background EEG [9]. In this paper, we employed NEO to detection evoked potential and segment neural signals for extracellular recordings of somatosensory cortex in rat.

Spike detection algorithms can broadly be divided into three categories. The first type includes algorithms that can be implemented in hardware and are based on user-specified thresholds. The simplest of these is amplitude threshold detection. The second type of algorithm is based on template matching. These algorithms essentially scan the entire recorded signal, for instances where segments of the signal are similar to a template that represents a typical spike morphology. The third approach uses signal transformations such as wavelet transforms and the nonlinear energy operator to enhance the signals and attenuate the background noise [10]. The NEO, also called the Teager energy operator, first characterized by Kaiser, estimates the square of the instantaneous product of amplitude and frequency of a sufficiently sampled signal. In this regard, the NEO may be considered superior to other energy estimators that simply average the square of the signal and are independent of frequency. NEO-based spike detection is attractive because of its ease of implementation and computational simplicity [11].

Teager proposed a simple nonlinear energy operator Ψ, given by

$$\Psi[x(n)] = x^2(n) - x(n+1)x(n-1) \qquad (1)$$

where $x(n)$ is the input extracellular neural signal at current time n and $x^2(n) - x(n+1)x(n-1)$ is the nonlinear energy operator. Let $x(n) = A\cos(\Omega n + \phi)$ where A is the amplitude of the neural signals, Ω is the frequency and is given by $\Omega = 2\pi f / f_s$ where f is the analog frequency and f_s is the sampling frequency, ϕ is the arbitrary initial phase in radians. While the sampling rate of the signal is greater than eight times the frequency of oscillation of the signal i.e. at least two sample points in each quarter cycle of the sinusoidal oscillation. The expected value of the output that a more generalized form of the Teager's algorithm for $x(n) = A\cos(\Omega n + \phi)$, can be written as

$$E[\Psi_g[x(n)]] = A^2 \sin(2\Omega)\sin(\Omega) \approx 2A^2\Omega^2 \qquad (2)$$

To detect these changes, a modified sliding temporal window method is used to generate the segmentation criterion (distance measure). For a given time instant n and a moving window length $2W$ are used to find the energy change in the window. Mathematically, the signal G_{neo} can be written as

$$G_{neo}(n) = \left| \sum_{m=n-W+1}^{n} \Psi(m) - \sum_{m=n+1}^{n+W} \Psi(m) \right|, \quad 2W: \text{moving window length} \qquad (3)$$

Experimenting with the proposed approach, it is found that, though reduced, the G_{neo} still generates some spurious redundant segment boundaries due to the inherent random fluctuations. It can be effectively reduced by applying a threshold procedure as the following,

$$T(n) = \max\left[G_{neo}(n - \frac{L}{2} : n + \frac{L}{2}) \right], \quad L: \text{moving window length} \qquad (4)$$

Another moving window size L can be chosen to increase or decrease the sensitivity of the threshold and is applied to obtain the threshold value $T(n)$. That is, by increasing L we reduce the number of segments generated and vice-versa. By applying Eq. (4) to Eq. (3), a new segmentation criterion, $G(n)$ can be derived,

$$G(n)=\begin{cases} G_{neo}(n) & if \quad G_{neo}(n)\geq T(n) \\ 0 & if \quad G_{neo}(n)<T(n) \end{cases} \qquad (5)$$

According to the thresholding energy change value $G(n)$, $G_{neo}(n)$ and $T(n)$ are compared to acquire a final boundary value.

3 Results

3.1 Microelectrode testing

Electrochemical impedance spectroscopy (EIS) is performed on a microwire probe array in an artificial cerebral spinal fluid (ACSF) at room temperature. The composition of the ACSF is NaCl 6603 mg/L, KCl 223 mg/L, NaH2PO4 165.5 mg/L, CaCl2 220.5 mg/L, MgCl2 203.3 mg/L, NaHCO3 2520 mg/L and Dextrose 5405 mg/L (Motta and Judy, 2005). An impedance spectrum analyzer IM6ex (IM6ex, ZAHNER-elektrik GmbH & Co. KG) is used. Thales software automatically supports all options and processes. A silver/silver chloride reference electrode and platinum counter electrode are utilized.

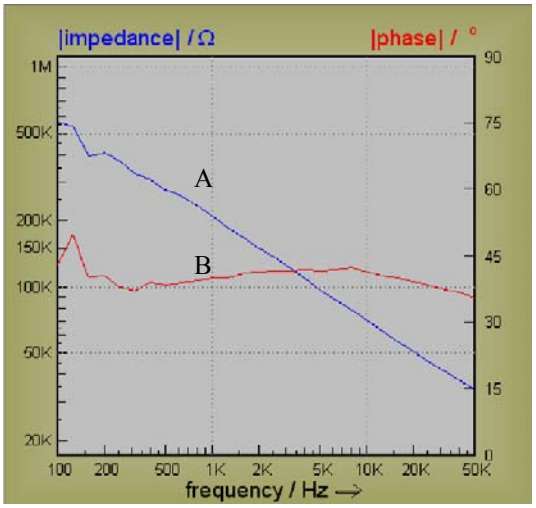


Fig.6 Relationships between impedance and frequency (mark A) and between phase and frequency (mark B) for channel 4 of a microelectrode, measured using EIS. The horizontal axle represents frequency; the left-hand vertical axis represents impedance and the right-hand vertical axis represents phase.

Measurements are made over a frequency range of 100 Hz to 50k Hz at open circuit potential with a sinusoidal perturbation voltage of 20 mV. The impedance spectroscopic measurements characterize the electrochemical properties of the electrode and ensure that the electrical integrity of the signal path is maintained after packaging and implantation in the brain. Figure 6 plots results for channel 4 of a six-channel microelectrode measured from the EIS. The impedance values of the channels associated with our proposed design, from EIS graph, are 200kΩ, 220kΩ, 225kΩ, 225kΩ, 190kΩ and 215kΩ, respectively. A mean impedance of 212.5kΩ, standard deviation of 13.15kΩ and coefficient of variation of 6.18% are obtained for six-channel microwires electrode at 1 kHz. The phases of the channels are 50deg, 55deg, 47deg, 40deg, 57deg, and 52deg respectively. The average phase is 50.17 degrees; standard deviation is 5.58 degrees and coefficient of variation is 11.12%. Observe the coefficient of variation of impedance and phase that the presented microwire array electrode is suitable for recording electro-physiological activity.

3.2 Cortical signal recording

Adult male SD rats (400–500 g) from the National Defense Medical Center Laboratory Animal Center are maintained in a colony room. All experiments are performed following the guidelines of the Institute of the National Defense Medical Center. All efforts are made to minimize animal suffering and the number of animals used. The observation site is located in the primary somatosensory cortex (S1). A six-channel microwire array electrode (50 μm diameter) is used to record extracellular cortical evoked potentials in the right S1HL and a reference electrode is placed in the cerebellum region by mechanical stimulation of a brush, as shown in Fig.7.

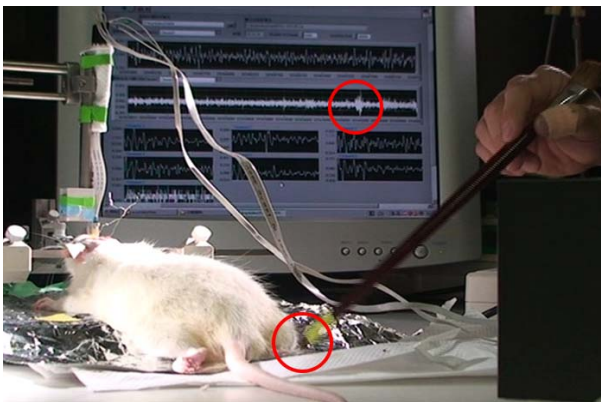


Fig.7 A video monitor shows the external stimulus and evoked signal simultaneously.

To record the neuron-evoked potential, a

neural signal recording system is used. The total gain of each channel is adjusted to 14,500 and the bandwidth of filter is 300Hz-3 KHz. The sampling rate of recording was 30k Hz; the whole recording system is based on a PC. The responses of an anesthetized rat to stimulation the claw of the left hind leg by scratching using a brush are obtained. In Fig. 8, the top window shows the period of 1 s; the middle window covers the period from 0.58 s to 0.76 s. The bottom window plots one section of the raw recording from 0.645 to 0.685 s. This section presents the potential evoked when the left back sole of the rat is stimulated.

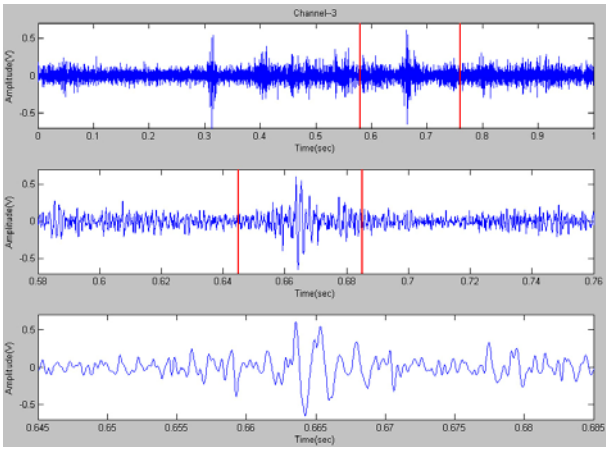


Fig.8 Evoked potential waveform when left back paw of rat is stimulated.

3.3 Evoked spike detection

3.3.1Noise reduction

Since the stimulation related neural signals of cortex are contaminated by environment, instrumentation and other biosignals noise like ECG, EMG, etc. Those noises are varied at time domain but stationary at spectrum domain. Therefore, the spectral subtraction can utilize to eliminate those noises and improve the signal-to-noise ratio. According to above idea, we recorded three types of neural signal; those are from on air, from S1HL without stimulation and from S1HL with stimulation by scratching the claw of the left hind leg using a brush. Taking channel 1 as an example, the signals of time and frequency domain are record respectively under three different states, as shown in Fig.9. The top window shows the information of on air, the left plot is the time domain and the right plot is the frequency domain; the middle window displays the information of without stimulation from S1HL; the bottom window presents the information of with stimulation from S1HL.

The procedures of spectral subtraction are executed for the noise reduction of extracellular neural signal according to above-mentioned five steps in the section 2.3.1. One sectional result of channel 1 after the processing of spectral subtraction is shown in Fig.10. The top window, Fig.10A, shows the spectral information of original and subtracted signal. The bottom window, Fig.10B, shows the time information of original and subtracted signal. The environmental and instrumental noise under neutral signal becomes clearly small after the processing the spectral subtraction for the extracellular cortical signal of channel 1. It is beneficial for the further signal analysis.

3.3.2Spike detection

According to experiments, the evoked neural signals of S1HL have different waveform and sound while the hindlimb of rat is stimulated or not via the synchronous observation of monitor sub-system. Through the processing of spectral subtraction, send the signal to next process of the NEO, to detect the time of spike from neural evoked potentials. The NEO can detect the change in amplitude and frequency of the signal. Therefore, the NEO can be utilized to detect the response points (time) of evoked potential. We can get the NEO segmentation criterion like green line under the top picture of Fig.11 when the procedure of Eq. (2) is carried out. Then the time of segmentation can be found as the red line while Eq. (3) has been executed. Due to the inherent random fluctuations and extrinsic interfering noise, the result still generates some spurious redundant boundaries, as shown in the top picture of Fig.11. In order to reduce the number of surplus and wrong boundaries of segment, the procedure of Eq. (4) is applied. The bottom picture of Fig.11 shows the final and correct time of evoked spike. And based on these detected points, we can segment the neural signals according to the length of further analytic need. Beside, the information of the monitor system are apply to verify the accuracy of spike detection that the information comprises the action of external stimulus, the waveform of neural signal and the voice of speaker, simultaneously. Following Eq. (3) and Eq. (4) using NEO must determine the parameter W and L. We choose the values of W= 90 (point) and L= 30W (point) to process the algorithm of NEO. Figure11 shows the result of the spike detection through the processing of NEO algorithm.

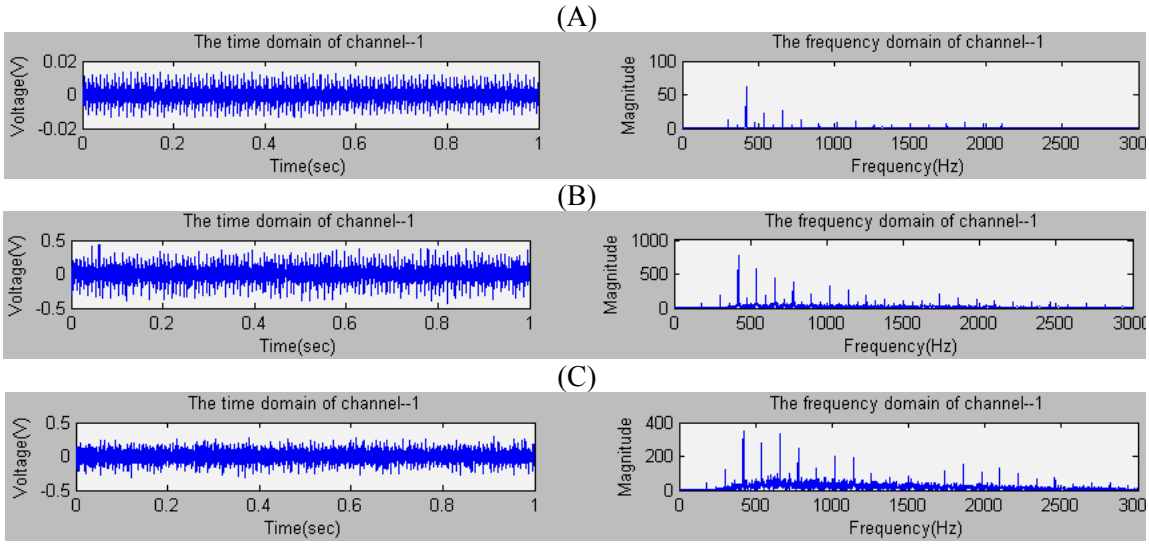


Fig.9 The recording signals of channel 1 are obtained separately from on air, from S1HL without stimulation and from S1HL with stimulation.

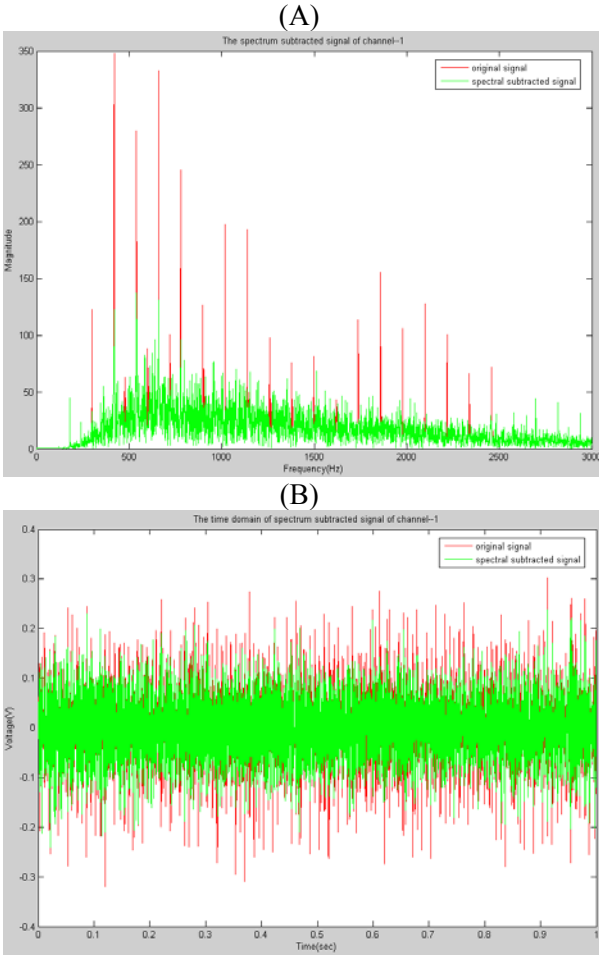


Fig.10 The result of channel 1 before and after the processing of spectral subtraction. The red line represents original signal, the green line represents subtracted signal.

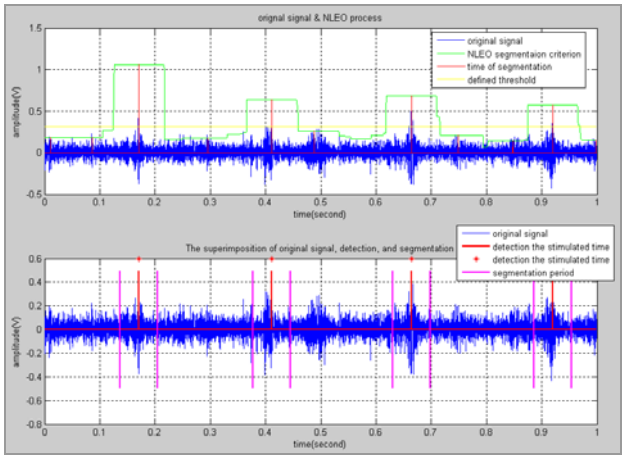


Fig.11 Let W=90, L=30W, can detect exactly the response points of spike

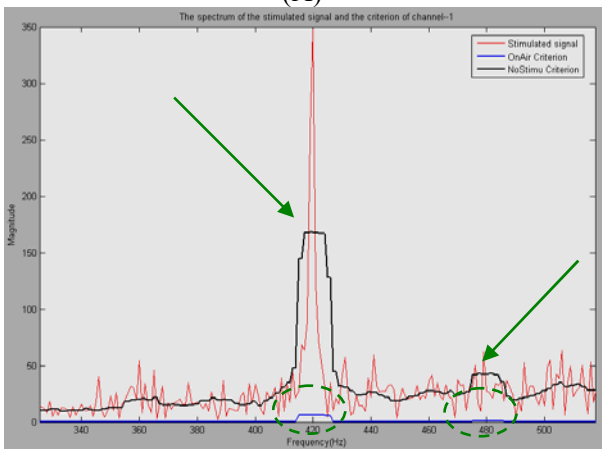
4 Discussion

4.1 Noise reduction

In the study, the method of spectral subtraction is used to reduce the environmental and instrumental noise as a preprocessing of further signal analysis. Accord with five steps of the spectral subtraction, we can get the result like Fig.12A when finish the front two steps. In Fig.12A, the blue and black lines indicate the mean values of on air and without stimulus, separately. The red line represents the spectral value of stimulated neural signals. The scope of the spectral subtraction is decided according to

the prominent section of the blue line. The value of red line is replaced to the value of front one point while the magnitude of the red line towers above the black line in the scope of the spectral subtraction. The value of red line is reserved if the magnitude of the red line compare with the black line is smaller. In Fig.12B, the green line represents the final result of spectral subtraction. When this method is utilized to reduce the noise signal on other biosignals in the future, it is necessary to decide the widths of spectral subtraction and the resultant value of subtracted.

(A)



(B)

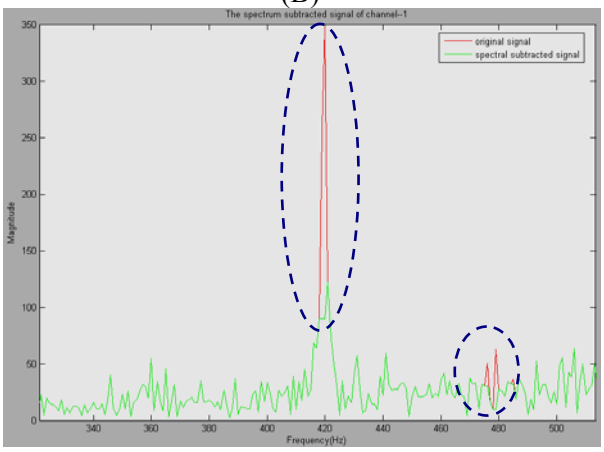


Fig.12 The process of spectral subtraction, A decides the widths of spectral subtraction and B compares the variation of finished execute.

A simple moving average is used to smooth the spectral data series and make it easier to spot trends when we execute the procedures of spectral subtraction for the noise reduction. An average is simply the sum of a data set divided by the number of data points. The three most popular types of moving averages are the simple moving average (SMA), the exponential moving average (EMA) and the weighted moving average (WMA). The simple moving average gives equal weight to all data points. By nature, it is the true average. The exponential and weighted moving averages give the most recent data points the highest rankings or weightings. Therefore, the simple moving average tends to lag compare with the exponential and weighted moving averages during large changes. In order to reduce the lag and improve the effect in simple moving averages, researcher can consider using EMA or WMA to replace SMA when the quality of processed signal is different.

4.2 Spike detection

To select the suitable W and L is very important, while the NEO method is used to detect the spike of somatosensory evoked potentials. Use the same neural signals as earlier experiment, we compare the difference after the NEO algorithm executed between W=90 (point), L=30W (point) and W=10 (point), L=10W (point). Figure 11 shows the fine effect while W=90 (point), L=30W (point). Figure 13 shows the poor result while W and L too small can not detect any response point. The experimental result appears that the moving window length of Eqs. (3)-(4) must be long enough to detect the spike of evoked potentials, but also can not too long to lose some transient conditions.

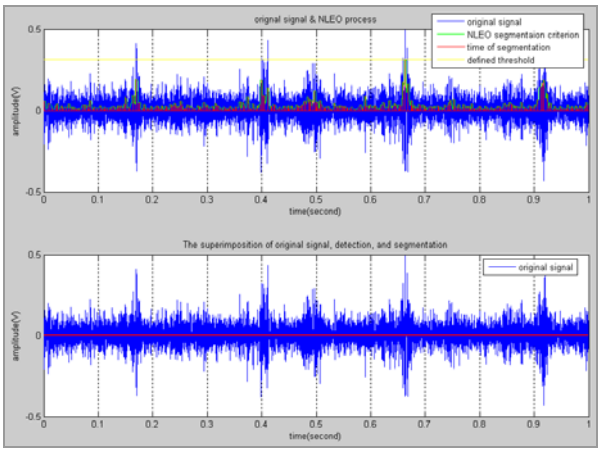


Fig.13 The results is poor after the same neural signals is executed with the different values of W=10 and L=10W.

According to above-mentioned the steps of spike detection, it is critical to select suitable W and L parameters for judgment the energy change of neural signal. Sometime, due to the inherent random fluctuations and extrinsic noise interference are more serious, the result of the NEO algorithm generates some spurious redundant boundaries. In order to avoid producing the wrong judgment, we can consider

cooperating with the simple threshold method after finishing the procedure of NEO algorithm. Consulting the result of this research experiment and the characteristic of evoked neural signal, we find the value of simple threshold method that it is appropriate to establish into 4.5-fold Vrms of the processed neural signal. In this work, the defined value of simple threshold method likes the yellow line under the top picture of Fig.11.

5 Conclusions

In the study, we present a multichannel extracellular recording system for the primary somatosensory cortex of rats. An assembled six-channel microwire array electrode has a mass of only 1.96 g. The material of the entire microelectrode costs less than US$ 1.5. The procedure described herein is relatively simple even for a novice worker to implement in-house. The presented microelectrode is successfully adopted to record the extracellular cortical signal. The developed recording system consists of the acquisition sub-system, the monitoring sub-system and the signal analyzing sub-system. The acquisition sub-system can capture the tens of micro voltage from the somatosensory cortex of rat. Through the signal analyzing sub-system, the recorded signal can be processing by many in-house developmental programs. We utilize the spectral subtraction method to reduce effectively the noise result from environment and instrument. Then the nonlinear energy operator algorithm is employed successfully to detect the spike of somatosensory evoked potentials. In order to evaluate easy the performance of proposed method, we especially plan to acquire the evoked potentials by external stimulation in the experiment. Via the monitoring sub-system, the information is apply to verify the result of spike detection and noise reduction, that comprises the action of external stimulus, the waveform of neural signal and the voice of speaker, simultaneously. The presented method can be employed further to detect the action potentials of spontaneous neural signal from the central nervous system or the peripheral nervous system in the future. Beside, the method can serve the application of medical diagnosis on disease.

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