Neural Conduction Measurement System
Home Assignment 2

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1 Introduction

Peripheral nerves system is composed of sensory nerves and motor nerves. In the former case, nerves conduct signals from a sense organ that is stimulated by external environment. The signals are transmitted to the central nervous system (CNS) to be processed. In response, CNS may deliver an active potential to motor nerves if they are not on the absolute refractory period, which drive the relevant skeletal muscle to contract. As a result, a person's sensation function and movement function can be weakened in case of the peripheral nerves system suffering injury. The proper therapy would be applied on the condition that the location of damaged nerve is confirmed.

The purpose of this assignment is that design a method to locate the injured motor nerve by measuring motor nerve conduction velocity (MCV), because the MCV of damaged nerve is slower than normal nerve's[1]. In this chapter, a diagram that contains MCV measurement processes is introduced. Requirements of every procedure are listed as well. In the second chapter, a detailed description is displayed, including signals acquisition and processing. Then, the specific method of locating injured nerve is explained with some plots and calculations.

1.1 Process of MCV Measurement

Nerve's field potential is not readily measured because of its small diameter fibers. The invasive electrodes, such as concentric needle electrodes, should be placed close to the nerve to measure signals. By contrast, the fiber of skeletal muscle is much thicker than nerve's. The surface electromyography (EMG) can be directly collected by surface electrode. Thus, in this design, MCV is detected by measuring and analyzing EMG signal. The concept of design is shown as Figure 1.1. The stimulus signal released by a stimulator is conducted by motor nerve, which induces skeletal muscle to contract. Meanwhile, the biopotential of muscle is obtained by an EMG amplifier. Then, the EMG signal is transmitted into the computer to be processed and calculated, deriving the MCV.

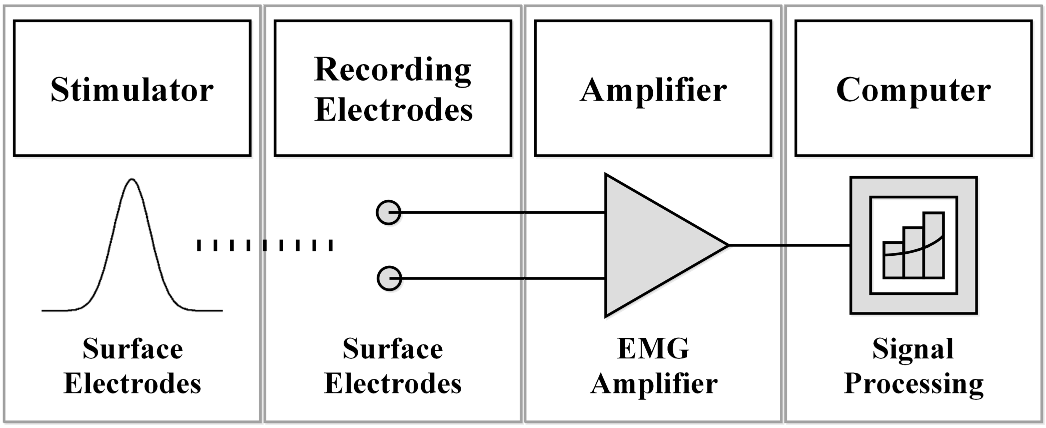

Figure 1.1: *Diagram of Neural Conduction Measurement System*

1.2 Requirements

Electrodes Surface electrodes are used to release stimulus as well as collect biopotential of muscle, which are not harmful to human body. A good choice is Ag/AgCl electrode, a kind of non-polarizable electrode, which is able to conduct current and alternate signals. Moreover, AgCl electrode has many advantages, such as small size, light mass, high reliable and durability[2].

EMG Amplifier The amplitude of EMG signal is in a range from 0.1mV to 5mV[3]. So, it's suitable that the gain of EMG amplifier is set to 1000. The frequency spectrum of EMG is from 0Hz(direct current signal) to 10kHz[3]. A typical pass band of the amplifier is from 20Hz to 10kHz. The motor artifact can be generated by the displacement of electrodes, which is a kind of low frequency noise. A 20Hz high pass filter is capable to remove low frequency noises, such as motor artifact[4]. A relative high value of the high cut off frequency insures a good precision of measuring method.

2 MCV Measurement System

In this chapter, three parts of MCV measurement system are separately described. The first part is EMG signal acquisition, which gain the muscle response after getting impulse transmitted by motor nerve. The next part is signal processing to improve the signal-noise ratio (SNR) of measured EMG. In the final stage, a practical measurement method is introduced to locate injured nerve. Calculation of MCV and relevant arguments are displayed both in flowchart and equations.

2.1 EMG Signal Acquisition

The process of collecting EMG signal is shown as Figure 2.1. A stimulator generates an impulse to stimulate the motor nerve. The signal is conducted to muscle, which arouses muscle response. Recording electrodes collect the surface EMG and import the signal into EMG amplifier. After being enhanced, the signal enters computer to be processed.

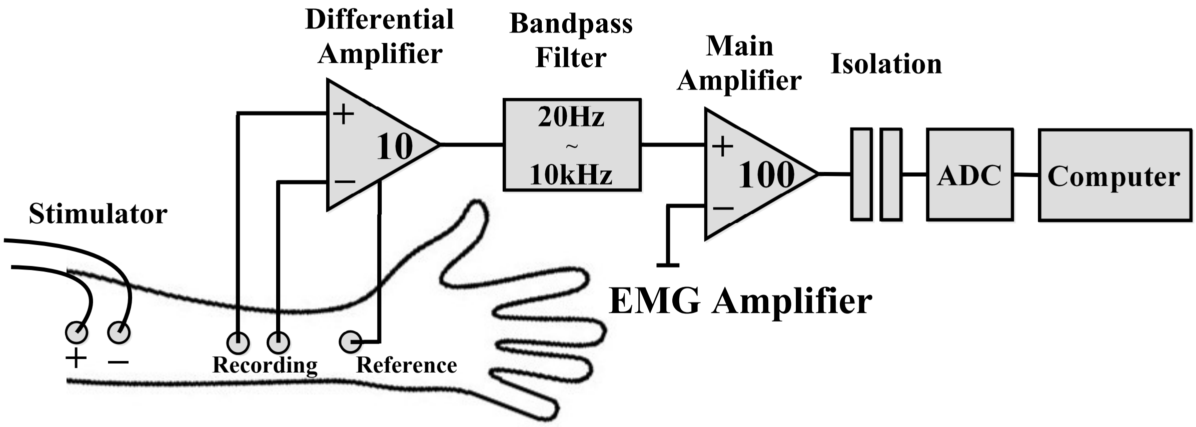

Figure 2.1: *Procedure of EMG Signal Acquisition*

2.1.1 Stimulator

A pair of surface electrodes, Ag/AgCl plates, is applied as a stimulator to incent motor nerve. One of these electrodes is cathode as the negative pole of stimulator, which is closer to recording site. The other one is anode, the positive pole, which is farther from recording site. Usually, the distance between cathode and anode is 2 to 3 cm. The intensity of stimulus is at least 150V(40mA), but no more than 400V(15mA) with the duration 0.2 msec[5]. To determine a proper threshold of intensity, in practical situation, the intensity of stimulus should be increased gradually, which leads to the growth of EMG signal. As the intensity reaches a certain value, the amplitude of EMG stops increasing. This value is the best choice of impulses intensity[6].

2.1.2 Recording Electrodes

Muscle response is gathered by surface electrodes. Since the EMG amplifier is a bipolar configuration, the input signal needs to be collected by two electrodes. At the same time, a reference electrode is also necessary. In order to strengthen electrical contact, the skin should be abraded or wiped electrode paste[2]. Reference electrode is ought to be placed at muscle tendon where is inactive to the impulse[6].

2.1.3 EMG Amplifier

As shown in Figure 2.1, EMG amplifier consists of four stages. The first one is a differential amplifier with a gain of 10. Then, a band pass filter is introduced to remove unwanted signals out of the range from 20Hz to 10kHz. After that, a main amplifier provides a high amplification about 100. An isolation amplifier, in the final stage, is utilized to separate the amplifier from subsequent equipment, protecting human body from being damaged by high voltage.

2.2 Signal Processing

After EMG signal being acquired, it has to be processed by a computer. An analog-digital conversion (ADC) is required to convert analog signal to discrete signal which can be handled by a compute. The discrete data is able to be stored as raw data, also it can be processed to increase the SNR. Then, the equipment displays the processed signal. Figure 2.2 shows a diagram of computer's components.

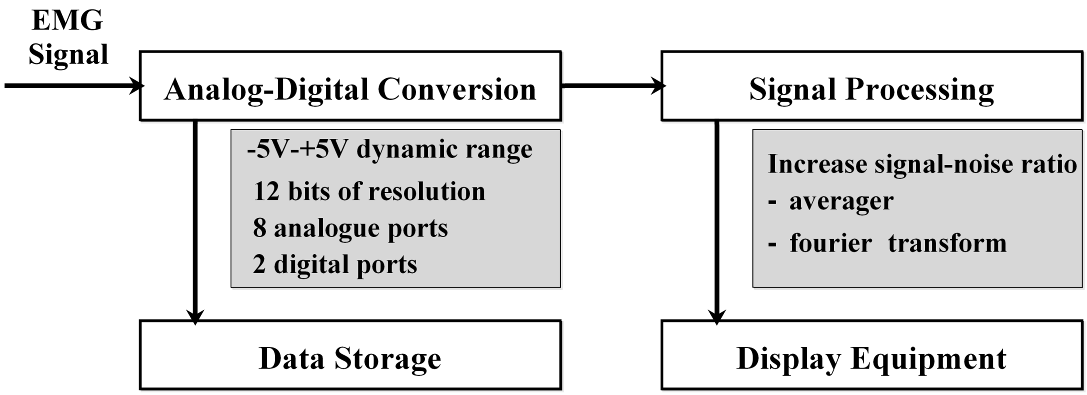

Figure 2.2: *Computer with ADC and Signal Processing*

2.2.1 Analog-Digital Conversion

The purpose of analog-digital conversion is to transform continuous analog signal into discrete digital signal. As shown in Figure 2.2, the converter, in this design, has a dynamic range of ±5V, its resolution is 12 bits, which means that the ADC can encode an analog signal between -5V and +5V into $(2^{12}-1)$ discrete levels. The resolution of the ADC can be calculated as Equation 2.1, which is 2.44mV. Thus, the changes of discrete signal can be obtained only when the changes of input analog signal exceed 2.44mV. The sampling frequency of ADC should be at least twice of the highest frequency of the input signal, which is 20kHz in this case.

$$Q = \frac{5-(-5)}{2^{12}-1} \approx 2.44mV \tag{2.1}$$

2.2.2 Signal-Noise Ratio

Computer processes the signal after receiving discrete data to promote the signal's SNR. SNR is a ratio of the wanted signal to the noise or squared ration of signals amplitude. The unit of SNR is dB. Its calculations are displayed in Equation 2.2 and 2.3[7], in which P_{signal} is the power of wanted signal, P_{noise} is the power of noise, A_{signal} is the amplitude of wanted signal and A_{noise} is the amplitude of noise. In this section, two method are recommend to promote SNR, which are averager and Fourier transform.

$$SNR = \frac{P_{signal}}{P_{noise}} = \frac{A^2_{signal}}{A^2_{noise}} \tag{2.2}$$

$$SNR_{dB} = 10log_{10}(\frac{P_{signal}}{P_{noise}}) = 20log_{10}(\frac{A_{signal}}{A_{noise}}) \tag{2.3}$$

Averager is useful to remove random noise, such as white noise. "When the stimulus is repeated, the same or a very similar response is repeatedly elicited."[3] As plenty of responses are superimposed together, random noises offset each other, but the amplitude of wanted signals significantly increase, resulting in the improvement of SNR. There is a simple example shown in Figure 2.3. Subplot (a) shows original signal. Then, a white noise whose amplitude is same as original signal's is added to make the SNR to be 1:1 (0dB), shown in (b). (c) displays the average of 100 noised signals. It is observed that the noise has been visibly reduced. The average signal's SNR is 100:1 (20dB). The average of 10000 noised signal is shown in (d), whose SNR is 10000:1 (40dB). The noise is almost eliminated.

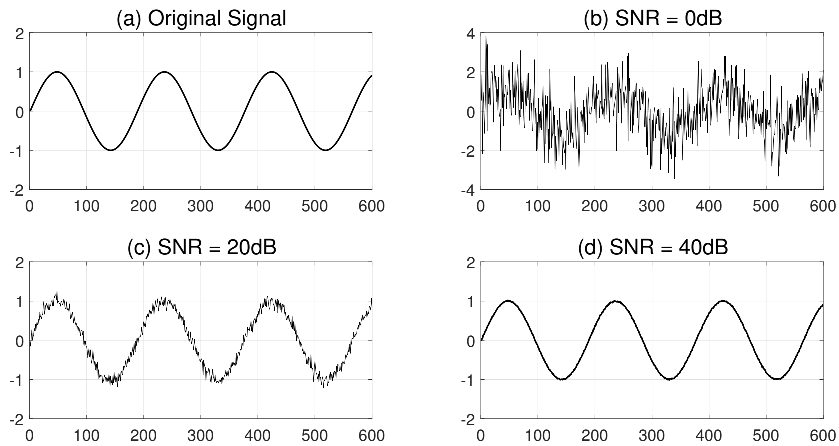

Figure 2.3: *Increasing Signal-Noise Ratio by Averager*

Fourier Transform is different from averager, it improves the SNR by analyzing signal's frequency spectrum and filtering to acquire or remove signal with a certain frequency. Figure 2.4 shows a simple case. The original signal (50Hz) is displayed in subplot (a). A noised signal is shown in (b), whose SNR is 1:1. After Fourier transform, the frequency spectrum of noised signal can be seen in (c). Obviously, signal with 50Hz has the largest magnitude, which is a wanted signal in this example. Then, the 50Hz signal, shown in (d), can be gained by a filter. It's the original signal.

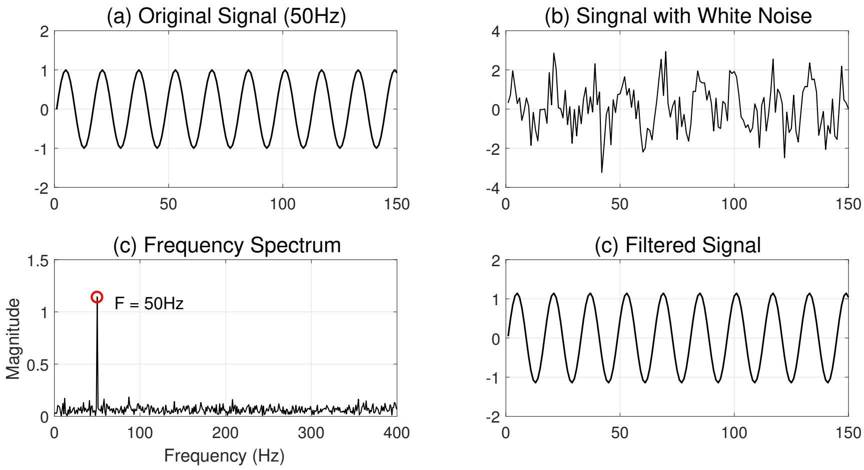

Figure 2.4: *Increasing Signal-Noise Ratio by Fourier Transform*

2.3 Method of Measurement

After the description above, an EMG signal with low noise has been acquired. To calculate MCV, EMG signals at different positions of limb should be measured separately to get conductive times. Then, the distances between each measurement position are also needed to be determined. In this section, take the upper limb for example to explain the selection of measurement positions and the computational process of MCV.

2.3.1 Positions of Recording Electrodes

Positions of recording electrodes are shown as Figure 2.5. There are four positions where should measure EMG signals, they are wrist, elbow, axilla and the base of neck[6]. These four sites divide the limb into three sections. The length of each section is D_1, D_2 and D_3. MCV of each section is ought to be measured separately, then compares it with normal value. For instance, the MCV of D_1 section is not within the normal range, which indicates that the injured nerve is very likely to locate in this part. Then, D_1 is separated into several parts to measure MCV again, finding a more precise location of injured nerve.

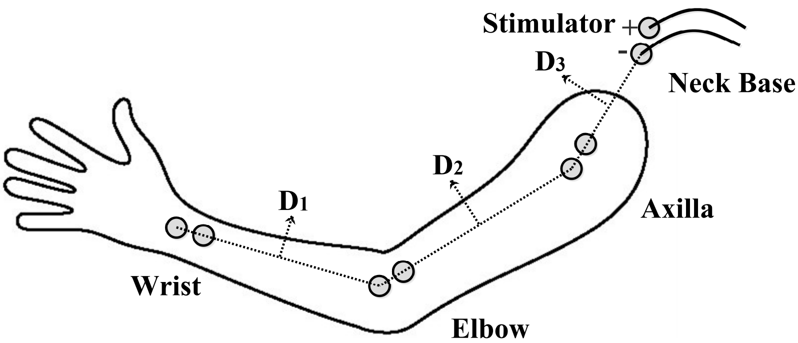

Figure 2.5: *MCV Measurement Positions*

2.3.2 MCV Calculation

The latencies of muscle response are different because of the different measurement positions. As shown in Figure 2.6, the latency of wrist muscle response is T_1, T_2 is the latency of elbow muscle response. The subtraction of T_2 and T_1 is the transmitting time of stimuli flows from elbow to wrist. The distance between wrist and elbow is divided by the transmitting time as shown in Equation 2.4, which elicits the MCV of this section. Then, compare this MCV with the normal value to judge whether the nerve in this section is unharmed. The normal conductive velocity of upper limbs motor nerves, such as ulnar nerve and median nerve, are no less than 49m/sec[8].

$$MCV_{D1} = \frac{D_1}{T_2 - T_1} \tag{2.4}$$

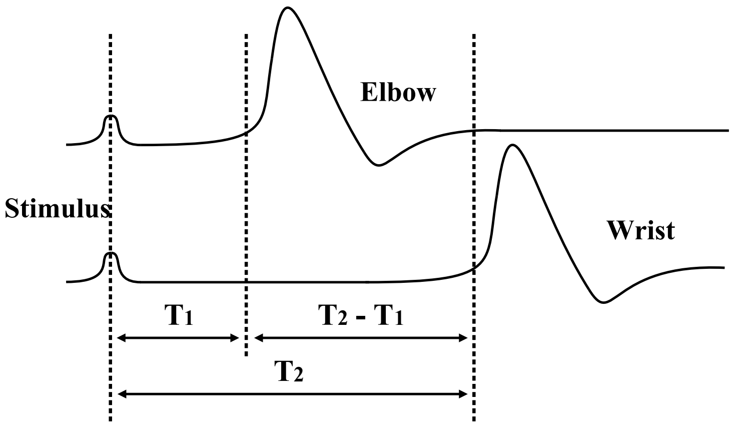

Figure 2.6: *Muscle Response at Wrist and Elbow*

3 Conclusion

In this assignment, a method of MCV measurement is designed to locate the injured motor nerve. A pair of surface electrode is applied to stimulate motor nerves to generate active potential. Muscle response is collected by recording electrodes at different positions of upper limb. Then, an EMG amplifier is utilized to enhance the signals, in which the amplification is 1000 and the pass band is between 20Hz and 10kHz. EMG analog signals are converted to discrete data by an ADC. The signals are processed by averager or Fourier transform to improve its SNR. In final, the MCVs of motor nerve in different sections are calculated. The site of damaged nerve can be determined by contrasting MCVs with normal values.

References

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