Surface EMG Network Analysis and Robotic Arm Control Implementation

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Abstract— An implementation for surface EMG network analysis and vertical control system of robotic arm is presented in this paper. The transmembranes are simulated by equivalent circuit and cable equation for propagation to be converted to circuit networks. The implementation is realized to be derived from the detecting EMG signal from 3 electrodes, and EMG transmembrane signals of human arm muscles are detected by several surface electrodes, high performance amplifier and filtering, converting analog to digital data and driving a servomotor for spontaneous robotic arm. The system is experimented by monitoring multiple steps vertical control angles corresponding to biceps muscle movement. The experimental results are that the vertical moving control level is measured to around 2 degrees and mean error ranges are lower 5%.

Index Terms— Surface EMG, electrode, robotic arm, transmembrane, cable equation, Servomotor control and equivalent circuit.

I. INTRODUCTION

IT is important to study transmembranes along the membrane of nervous system in biomedical engineering. The neurotransmitters are to convert human's thought, consciousness and external stimulus to ionic electric signals over the afferent neuron, interneuron and efferent neuron of the excited tissues. These researches result in EMG (Electromyography), EEG (Electroencephalogram), ECG (Electrocardiogram), EOG (Electrooculography) and ERG (Electroretinography).[1-3] These systems measure heart, muscle, and brain activity over time by measuring electric potentials on the surface of living tissue. There are clinical and prosthetic controls in EMG signal processing. The signal processing has been studying the control of arm prosthesis. Common applications of the EMG signal are to determine the activation timing of the muscle when the excitation to the muscle begins and ends, to estimate the force produced by the muscle, and to obtain an index of the rate at which a muscle fatigues through the analysis of the frequency spectrum of the signal. Nervous stimuli and muscle contractions can be detected by measuring the ionic current flow in the body. This is accomplished using a biopotential electrode. There

are surface and needle type of EMG electrodes. It is more comfortable and convenient to utilize the surface in acquiring signals in safety than the needle. They are used in medical area and industrial robots. That is, EMG has been applying to human interface system for the handicapped, disability in biomedical electronics and industrial systems. The signals acquired by electrode sensor have been used for the hand gestures and movements, and implemented in the position control of prosthetic arm for amputees and applied to rehabilitation with robotic devices. The position control estimates the intended torque of the stepping motor and provides sufficient information for an effective force control of the arm handicapped as well.[4-7] The system is required to control robotic arm movement in detail according to neurotransmitter signals of arm movement for user's safety spontaneously.

This study is focused on the implementation for vertical robotic arm control system with fine angles. The implementation will be processed by the neurotransmitter signal sensing, amplifier and filtering design, signal processing and system experiment. The sensor has several electrodes, the amplifier and filtering is high performance and low noise and HPF/LPF. The signal processing reveals frequency by Fourier transform, and system performance is measured by relation between EMG signals and servomotor through the iterative experiments.

II. EMG NETWORK ANALYSIS AND ROBOTIC ARM CONTROL

A. EMG Network Analysis

EMG signal of nervous system is required a stimulus to convert to electric system in operating the neuron over the membranes. The signal results from excitable tissue. The travel of muscle via axon is directed from the cranial and spinal cord to a muscle. Interneurons and efferent neurons over the axon are cells that they respond to the chemical transmitter by generating the burst of APs (action potential). The axon is a poor conductor severely attenuated. AP is voltage spikes 100mV high and a graded potential. The minimum interval of the AP train is 4 ms, refractory period. The AP of the efferent neuron from the interneuron is able to be converted to RLC equivalent network as shown in Fig. 1 to find the electric characteristics. The equivalent circuit is composed of the interneuron input potential v_i , RLC passive elements and

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the graded potential output v_o. The inductance of nerve fiber can be neglected. It is swamped out by axoplasmic resistance.
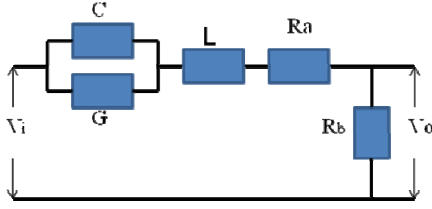

Fig. 1. RLC network of AP.

The transfer function H of this linear network is defined as output/input applying the Laplace transformation, $H=V_o(s)/V_i(s)$. The corresponding input potential for AP is given by equation (1), where k is final value after adaptation, τ_1 is time constant of the leading edge, and τ_2 is adaptation time constant.

$$V_o(s) = V_i[k/s = 1/(s+1/\tau_1)+(1-k)/(s+1/\tau_2) \quad (1)$$

For the preceding numerical example, $V_i(s)=0.02/s$, k=0.1 τ_1=0.8s, τ_2=2.5s, H is given by equation (2), and the simulation is shown in the Fig. 2. The simulation is given in c=0.89, b_1=0.4, a_1=1.25 and a_2=0.045 for instance.
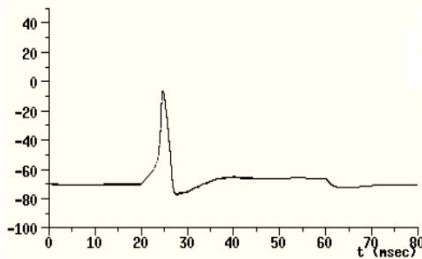
$$H(s) = \frac{c(s+b_1)}{(s+a_1)(s+a_2)} \quad (2)$$

Fig. 2. Simulated AP output waveform.

The transmembrane cable equation derives from Hodgkin and Huxley action potential used the equivalent circuit of Fig. 3 for the short length of an axon. G_n is the equivalent conductance of the membrane to sodium ions, G_k is the conductance to potassium ions, G_c is the nominal conductance to chloride ions, and these total membrane resistance is $R_m [\Omega.m]$. $C_m [F/m]$ is a membrane capacitance.

The voltage sources are equivalent values at rest. E_n small sodium ion current flows into the axoplasm, E_k small potassium current flows out of the axoplasm, and E_c chloride ions flow out of the axoplam. R_i and $R_e [\Omega/m]$ are denoted by the intracellular and extracellular resistances per length along the fiber.
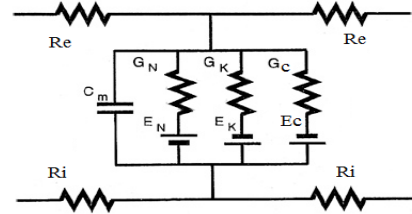

Fig. 3. Transmembrane equivalent network.

The standard cable analysis can be used to derive the cable equation for the transmembrane potential V_m as defined by equation (3), where τ is the time constant $R_m C_m$, and L is the length constant $(R_m/(R_i+R_e))^2$.

$$L^2 \frac{\partial^2 V_m}{\partial x^2} = \tau \frac{\partial V_m}{\partial t} + V_m \quad (3)$$

To approximation, a fiber can be represented as the infinitely long RC cable where R is series axoplasm resistance and C is shunt membrane capacitance from Fig. 1. This fiber cable equation [1] is given by equation (4) from Laplace transformation with general solution. The output waveform comes from the inverse Laplace transform. The membrane propagation is simulated as shown in Fig. 4. For example, R is $1.59/d^2$ using resistivity ρ 125[Ω.m], C is 0.0296d, accordingly RC is 0.047/d, where d is axon's diameter, 0.02mm. This signal is transmitted from cranial nerve and spinal cord to arm muscle to control the servomotor.

$$\frac{\partial^2 V(s)}{\partial x^2} = sRCV(s),$$
$$V(s) = V_m \exp(-x\sqrt{sRC}), \quad (4)$$
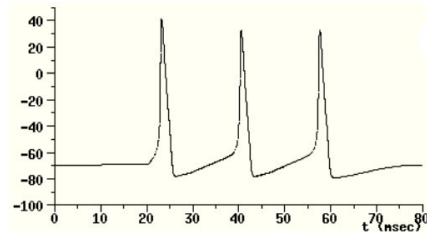$$V = \frac{V_m x}{2t^{3/2}}\sqrt{RC/\pi}\exp(-\frac{x^2 RC}{4t})$$

Fig. 4. Simulated membrane propagation.

B. Robotic Arm Control Implementation

Robotic arm implementation is based on the surface EMG to acquire the membrane action potential as shown in Fig. 5 of control system implementation. An electrode is *silver/silver choloride* (Ag/AgCl) because of its low half-cell potential of approximately 220 mV and its ease of manufacturability. Ag/AgCl electrodes are nonpolarized electrodes. They

allow current to pass across the interface between the electrolyte and the electrode. Nonpolarized electrodes are better than polarized electrodes in terms of their rejection of motion artifacts and their response to defibrillation current
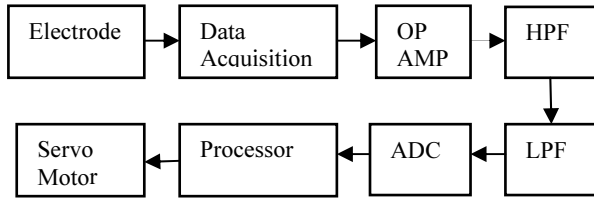

Fig. 5. System implementation blocks.

Both motion artifacts and defibrillation events can charge up the capacitance from the electrolyte and electrode interface. The AgCl layer lowers the impedance of the electrode. This is important at low frequencies near dc, where EMG measurements are taken. Skin to electrode impedances at 10 Hz using silver/silver chloride electrodes, with the skin properly prepared, are typically about 5 kΩ. A simplified equivalent circuit for the electrode is shown in Fig. 6. Analysis of the circuit reveals the signals acquisition problem due to the RC components. Resistor R_1 and capacitor C_1 are due to the effects at the electrode/cell interface and are frequency dependent. These values fall off to a negligible point at a rate of $1/(2\pi f)^2$ and are considerably lower than R_2 and C_2.
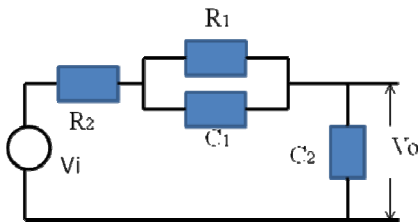

Fig. 6. Electrode equivalent circuit.

There are several important properties to consider in a pre-amplifier: High common mode rejection ratio, Very high input impedance, Short distance to the signal source and Strong DC signal suppression. The common mode rejection ratio provides an index on the extent to which common signal components are attenuated from the signal. As such it is desirable to have the highest common mode rejection (CMR) possible. At the moment the best CMRR that can be realistically achieved with current technology is about over 100 (dB/Octave)

The signals had been amplified to recordable levels. The final step was to ensure that there would only be frequency content between 20 [Hz] and 420 [Hz]. To do this, the amplified signal was passed through a second-order highpass filter implemented with 20 [Hz] cutoff frequency and a second-order lowpass filter with a 420 [Hz] cutoff frequency. Second order filters were selected as a first order filter did not have sharp enough frequency

cutoffs. Highpass filtering is necessary because movement artifacts are comprised of low frequency components. Lowpass filtering is desirable to remove high frequency components to avoid signal aliasing.

Measuring and accurately representing the EMG signal depends on the properties of the electrodes and their interaction with the skin, amplifier design, and the conversion and subsequent storage of the EMG signal from analog to digital conversion. The quality of the measured EMG is often described by the ratio between the measured EMG signal and unwanted noise contributions from the environment. The goal is to maximize the amplitude of the signal while minimizing the noise. Assuming that the amplifier design and process of A/D conversion exceed acceptable, the signal to noise ratio is determined almost exclusively by the 3 electrodes.

Processor controls the servomotor for a robotic arm from ADC. Typical servomotors are very useful in different kinds of small robotic applications because of compact and inexpensive. RC servomotor includes a built-in DC motor, gear mechanism, position feedback control loop (potentiometer), and motor drive circuit. Servos refer to an error sensing feedback control which is used to correct the performance of a system. The pulse width modulation (PWM) technique makes reference to the position of the output shaft of the motor. The pulse width is converted into an equivalent voltage that is compared with that of signal from the potentiometer. That has DC motors equipped with a servo mechanism for precise control of angular position, be moved to a desired angular position by sending PWM signals. The motors usually have a rotation limit from 90° to 180° or 360. The rotation is restricted in between the fixed angles.
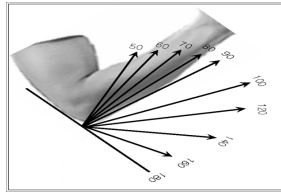
III. EXPERIMENT AND RESULTS

The experiments are taken by signal acquisition to 8 persons to control vertical arm, ADC 10bits and sampling frequency 1000 [Hz] for EMG, and by servo control from EMG between human and robot arm. The biceps signal is detected strongly in bending arm for the arm control system. The reference electrode is positioned at 2cm down from the biceps and the ground electrode is placed at 3 cm outside to control the servomotor as shown in Fig. 7 (a) and (b). The spectral characteristics of the EMG signal will reflect the properties of a fixed set of muscle fibers in the region of the electrode. Also, the frequency spectrum of the EMG signal will be independent of any trigonometric factor that would provide an erroneous estimate of the conduction velocity. The resultant value of the conduction velocity affects the EMG signal by altering the temporal characteristics of the EMG signal, and consequently its frequency spectrum as shown in Fig. 7 (c) and (d).

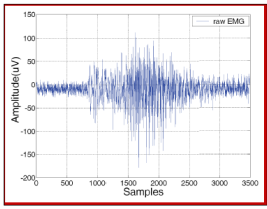A servo angles are controlled by impulse, and the centering is important. A servo precision positioning

makes them ideal for robotics, since servos are self contained with control loop circuitry, drive circuits, servo position and speed control. Servos actively move to hold the position.
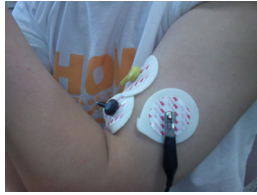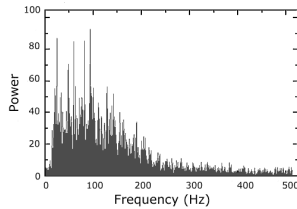

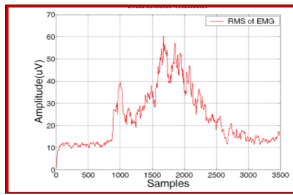(a) Electrodes position   (b) Servo control angles

(c) Detected signal   (d) Frequency spectrum

(e) RMS signal

Fig. 7. EMG electrodes and servo, and time and frequency outputs.

If a servo is instructed to move in the clockwise position and an external force is present and pushing against the servo, the servo resist being moved out of that position or continue to try and move to the instructed position, even if the servo arm is incorrectly placed on the motor shaft, until power off. It is for the reason that servo output arm or wheel should be placed into the neutral position before installation. The Table I shows the vertical arm angles and impulse intervals at the averages.

TABLE I
SERVOMOTOR IMPULSE TIMES AND ANGLES

interval	1	2	3	4	5	6	7	8	9	10
time	180	160	140	120	100	90	80	70	60	20
angle	0.7	0.9	1.0	1.2	1.4	1.5	1.6	1.7	1.8	2.0

The error ranges of robotic arm control at the average are measured by 8 persons in repeating every 10 times. They take a rest for 5 minutes to minimize the muscle fatigue. The measured levels are taken by the minimum and maximum placed by 50º=0 and 180º=100 because individuals EMG amplitude of the waveforms are different. That results in 5% lower of error as shown in the Fig. 8, which bottom curve is mean error, top curve indicates maximum error and mid curve shows minimum error.
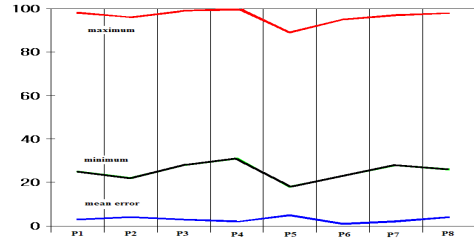

Fig. 8. Mean error ranges for practical control.

IV. CONCLUSIONS

An implementation for surface EMG network analysis to vertical control system of robotic arm is presented in this paper. The system is realized to derive from the fine EMG transmembrane signals of human arm muscles are detected by several surface electrodes, high performance amplifier and filtering, converting analog to digital data and driving a servomotor for spontaneous robotic arm control. The system is experimented by monitoring multiple steps vertical control angle corresponding to voluntary arm movements. The experimental results are that the vertical arm control level is measured to around 2 degrees and mean error is lower 5%. The system will be improved to be 3D controller for the handicapped in the future.

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