33rd Annual International Conference of the IEEE EMBS
Boston, Massachusetts USA, August 30 - September 3, 2011

Control of A Myoelectric Arm Considering Cooperated Motion of Elbow and Shoulder Joints

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Abstract— **In order to improve the quality of life of persons who lost their limb due to an accident or a sickness, many myoelectric artificial arms have been proposed. To control the motion of the elbow joint of the myoelectric arm, the EMG signals of the biceps brachii and the triceps brachii muscles are frequently used as input signals. However, since both muscles are the biarticular muscles between the shoulder joint and elbow joint, the amount of the EMG signals of these muscles are affected by the motion of the shoulder joint. In this paper, a control method for a myoelectric arm is proposed in order to cancel the influence of the shoulder joint motion on EMG signals is removed by using the neuro-fuzzy modifier in order to realize proper elbow motion. The effectiveness of the proposed method has been evaluated by performing experiments.**

I. INTRODUCTION

ARTIFICIAL limbs are useful for persons who lost their limb due to an accident or a sickness. Especially, in recent years, many myoelectric artificial arms have been developed [1]-[4]. In these myoelectric arms, the skin surface electromyogram (EMG) signals of amputee's stump or residual muscles are used as the input signal. Most of these myoelectric arms for the above elbow amputees provide elbow flexion/extension motion. Some myoelectric arms can perform the forearm supination/pronation motion or hand grasp/release motion in addition to the elbow motion. Commercially available expensive cosmetic prostheses offer a natural appearance and simple control. However, compared with a human upper-limb, these myoelectric arms have less degree of freedom (DOF) and its dexterity is relatively poor. A person performs various tasks with the upper-limb in daily life activities. The myoelectric arms which have the limited DOFs cannot achieve most of these motions properly. Although there are the myoelectric arms which can generate multi-DOF motions for above elbow amputees [5]-[7], none of these provides a combination of forearm and 2 DOFs wrist motions except the myoelectric arms designed for above wrist amputees [8].

In order to improve the quality of life of above elbow amputees and to increase their mobility in daily life activities, a 5-DOF myoelectric arm has been proposed [9],[10]. This myoelectric arm can generate the elbow flexion/extension motion, the forearm supination/pronation motion, the wrist flexion/extension and radial/ulnar deviation motion, and the hand grasp/release motion. In the cases of above wrist amputees, there is a strong possibility that the muscles which are used to generate the wrist motion or hand motion still remains. Therefore, the control of the myoelectric arms for above wrist amputees by EMG signals is relatively easy. On the other hand, in the cases of above elbow amputees, the muscles which are used to generate the forearm, wrist and hand motions do not remain, and the muscles which are used to generate the elbow flexion/extension motion may remain. For this reason, in the control of the 5-DOF myoelectric arm, fuzzy rules and an artificial neural network are used [10]. The forearm and wrist motions are controlled using an artificial neural network. This artificial neural network classifies the activities of a daily life of an amputee using the kinematics of the amputee's shoulder and elbow of the myoelectric arm. The elbow and hand motions of the 5-DOF myoelectric arm are controlled based on EMG signals from the biceps brachii and the triceps brachii muscles using fuzzy control rules. However, both the biceps brachii and the triceps brachii muscles are the biarticular muscles between the shoulder joint and elbow joint. Therefore, these EMG signals are influenced by the shoulder joint motion.

In this paper, the control method of the elbow motion of the myoelectric arm is proposed. In the proposed control method, the influence of the shoulder joint motion on EMG signals is removed in order to realize proper elbow motion. The effectiveness of the proposed method has been evaluated by performing experiments.

II. 5-DOF MYOELECTRIC ARM

The myoelectric artificial arm [9][10] which is used in this study is shown in Fig. 1. This artificial arm contains five DC motors with encoder, and can generate the elbow flexion/extension motion, the forearm supination/pronation motion, the wrist flexion/extension and radial/ulnar deviation motion, and the hand grasp/release motion. In normal human forearm, the radius bone of the human forearm crosses over the ulna bone during the pronation motion. On the other hand, the positions of these two bones are parallel during the supination motion. In the myoelectric arm, this human forearm mechanism is mimicked and the two shafts are located instead of the radius bone and the ulna bone. Furthermore, these shafts are used to connect the wrist part with the forearm. The wrist and hand motions are controlled via wires.

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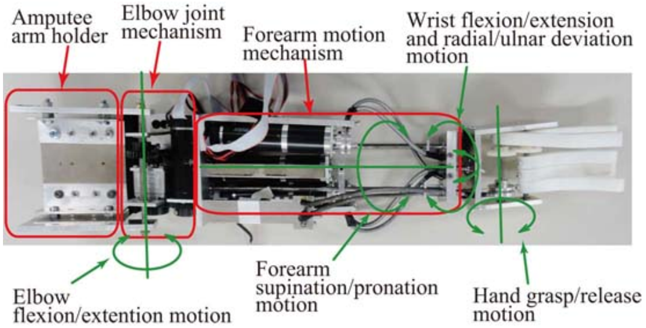
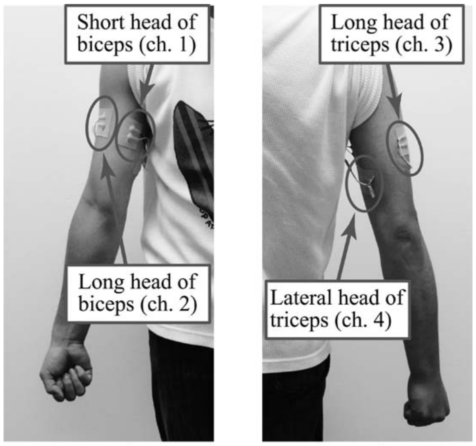


Fig. 1 5-DOF myoelectric arm.



Front view Rear view

Fig. 2 Location of the EMG Electrodes.

In addition to the myoelectric arm as shown in Fig. 1, a 3-axis acceleration sensor is used in order to measure the shoulder angle of an amputee.

III. CONTROL METHOD

In this paper, we assume that EMG signals of a biceps brachii and a triceps brachii of an amputee can be measured. The locations of EMG electrodes are shown in Fig. 2. As shown in Fig. 2, four channels of EMG signals are measured and used as input signals to the myoelectric arm.

To control the elbow motion of the myoelectric arm with EMG signals of the biceps brachii and the triceps brachii, the influence of the shoulder joint motion on EMG signals needs to be removed. In this study, the influence of the shoulder joint motion on EMG signals is removed by the neuro-fuzzy modifier. Since a raw EMG signal is not suitable for control input, the feature of the EMG signal is extracted by calculating Root Mean Square (RMS). The RMS calculation is expressed as follows.

$$ch_j = \sqrt{\frac{1}{N}\sum_{i=1}^{N} v_{ji}^2} \tag{1}$$

where ch_j is the RMS value of the EMG signal measured in channel j, N is the number of samples in a segment (N=300), and v_{ji} is the voltage of the EMG signal measured in channel j at i^{th} sampling. In this study, the sampling frequency is 2 kHz. The torque of the elbow joint can be calculated based on the RMS values as follows.

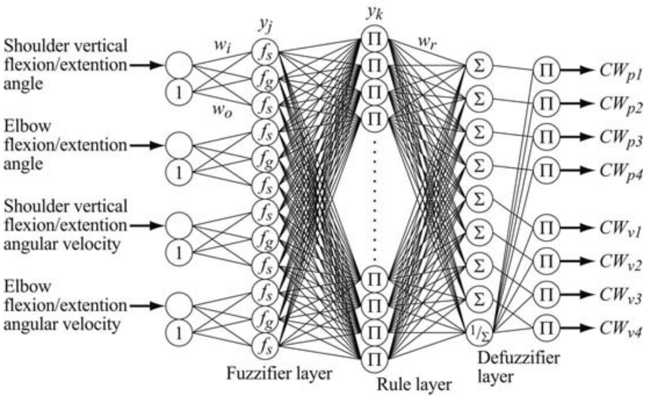


Fig. 3 Neuro-Fuzzy Modifier.

$$\begin{aligned}\tau_e = \ & w_{r,p1}ch_1 + w_{r,p2}ch_2 + w_{r,p3}ch_3 + w_{r,p4}ch_4 \\ & + w_{r,v1}(ch_1)' + w_{r,v2}(ch_2)' + w_{r,v3}(ch_3)' + w_{r,v4}(ch_4)'\end{aligned} \tag{2}$$

where τ_e is the torque of the elbow joint. $(ch_j)'$ is the differential of ch_j with respect to time. $w_{r,pj}$ and $w_{t,vj}$ are the weight values for ch_j and $(ch_j)'$, respectively. The weight values in eq. (2) are adjusted in real time according to the upper-limb posture by multiplying coefficients generated by a neuro-fuzzy modifier which is shown in Fig. 3 [11]. This adaptation technique with the neuro-fuzzy modifier enables the controller to adjust itself to be suitable for any posture of any person. $w_{r,pj}$ and $w_{t,vj}$ are adjusted by multiplying the output coefficient from the neuro-fuzzy modifier. When a person stretches the arm to a target object, the trajectory of the person's hand has a tendency to become straight line. In the control method, this human characteristic is considered. The hand force vector is calculated as follows in order to estimate the amputee's motion intention.

$$\boldsymbol{F}_{hand} = \boldsymbol{J}^{-\mathrm{T}}\begin{bmatrix}\tau_s \\ \tau_e\end{bmatrix} \tag{3}$$

$$\boldsymbol{F}_{avg} = \frac{1}{N_f}\sum_{k=1}^{N_f}\boldsymbol{F}_{hand}(k) \tag{4}$$

$$\boldsymbol{F}_{final} = \frac{1}{2}\left(\boldsymbol{F}_{hand} + \boldsymbol{F}_{avg}\right) \tag{5}$$

where $\boldsymbol{F}_{hand}$ is the hand force vector. τ_s is the torque of the shoulder joint and $\boldsymbol{J}$ is the Jacobian matrix. τ_s is calculated from the shoulder joint angular acceleration. The shoulder joint angular acceleration is calculated based on the shoulder joint angle which is measured by a 3-axis acceleration sensor. The moment of inertia of an amputee is calculated based on the results of [12]. In eq. (4), $\boldsymbol{F}_{avg}$ is average of $\boldsymbol{F}_{hand}$ in N_f number of samples. Finally, the joint torque command vector is calculated as follows based on $\boldsymbol{F}_{final}$ in eq. (5).

$$\begin{bmatrix}\boldsymbol{\tau}_{s,motor} \\ \boldsymbol{\tau}_{e,motor}\end{bmatrix} = \boldsymbol{J}^{\mathrm{T}}\boldsymbol{F}_{final} \tag{6}$$

where $\tau_{s,motor}$ and $\tau_{e,motor}$ are the joint torques of the shoulder joint and the elbow joint, respectively.

The hand motion is controlled based on the fuzzy control rules as shown in Table 1 [10]. Basically, the hand grasp motion is generated when both the biceps brachii and the triceps brachii are activated simultaneously. On the other hand, the hand remains in release position when either the biceps brachii or the triceps brachii is not working.

Table 1 Hand control algorithm

Rule-01: IF EMG ch.1 is PB and EMG ch.4 is PB
THEN Motor is 0.3 [Nm]
Rule-02: IF EMG ch.1 is PS and EMG ch.4 is PB
THEN Motor is 0.24 [Nm]
Rule-03: IF EMG ch.1 is PB and EMG ch.4 is PS
THEN Motor is 0.24 [Nm]
Rule-04: IF EMG ch.1 is PS and EMG ch.4 is PS
THEN Motor is 0.21 [Nm]
Rule-05: IF EMG ch.1 is ZO and EMG ch.4 is ZO
THEN Motor is -0.3 [Nm]
Rule-06: IF EMG ch.1 is PS and EMG ch.4 is ZO
THEN Motor is -0.21 [Nm]
Rule-07: IF EMG ch.1 is ZO and EMG ch.4 is PS
THEN Motor is -0.21 [Nm]

The forearm and wrist motions are controlled based on the classification by the artificial neural network [10]. In this controller, 10 kinds of activities in daily life which are important and frequently performed in daily living are considered. The kinematics of the shoulder flexion/extension, abduction/adduction, internal/external rotation, and elbow flexion/extension motion, are used as the input signals for the classifier. For the classified activity, the desired trajectory of the hand is estimated based on the nature of the task, and the inverse kinematic technique is applied to calculate the desired the forearm and wrist motions.

IV. EXPERIMENTS

Experiments were carried out to evaluate the effectiveness of the proposed controller for the elbow motion of the myoelectric arm. In the experiments, the myoelectric arm was fixed to a frame as shown in Fig. 4. In the proposed controller, we assume that the EMG signals of a biceps brachii and a triceps brachii of an amputee can be measured. The subjects in the experiments were healthy young men (A: 28 years old, B: 21 years old, and C: 23 years old) instead of an amputee. The angle measurement tool was located on the subject's upper-arm as shown in Fig. 4. The angle measurement tool has a 3-axis acceleration sensor and an encoder in order to measure the shoulder and elbow angles of the subject. The influence of the gravity on the motor of the myoelectric arm's elbow joint is changed depending on the shoulder joint angle of an amputee. In the experiments, we calculated the virtual gravity and added the correction torque because the shoulder joint angle of the myoelectric arm did not change according to the motion of the subject's shoulder joint in the experiment as shown in Fig. 4.

At first, the subjects moved only elbow joint when the shoulder vertical flexion angle is 0° or 90°. The experimental results are shown in Figs. 5 and 6. Figure 5 shows the result when the shoulder vertical flexion angle is 0°, and Fig. 6 shows the result when the shoulder vertical flexion angle is 90°. In Figs. 5 and 6, (a) shows the RMS values of EMG signals, and (b) shows the elbow angles of the subject A and myoelectric arm. In the cases of results shown in Figs. 5(b) and 6(b), the motions of the subject's elbow joint were similar. However, the RMS values of EMG signals were different as shown in (a) because the subject's shoulder vertical flexion angles were different in both cases. In the proposed controller, the weight values in eq. (2) are adjusted in real time according to the posture of the upper-limb by using the neuro-fuzzy modifier. Therefore, the myoelectric arm could follow the subject's motion as shown in Figs. 5(b) and 6(b) even though the RMS values changed depending on the posture of the subject's upper-limb. Similar results were obtained with the subjects B and C.

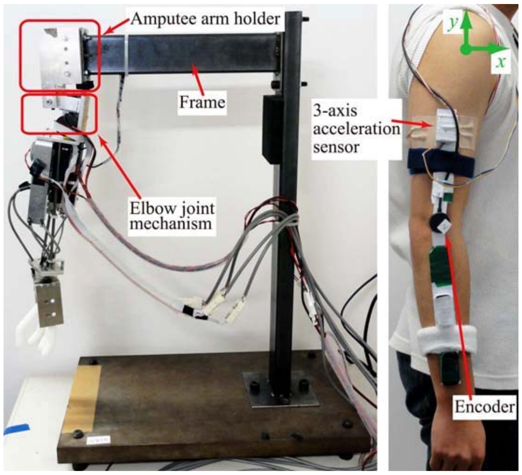
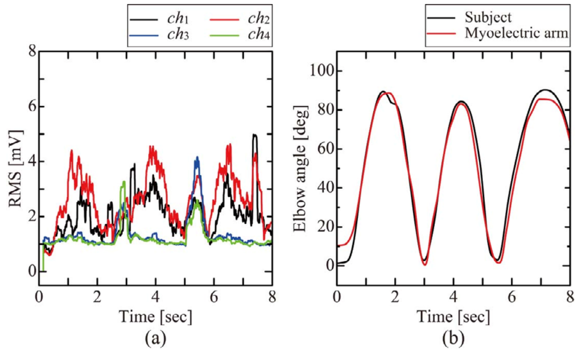
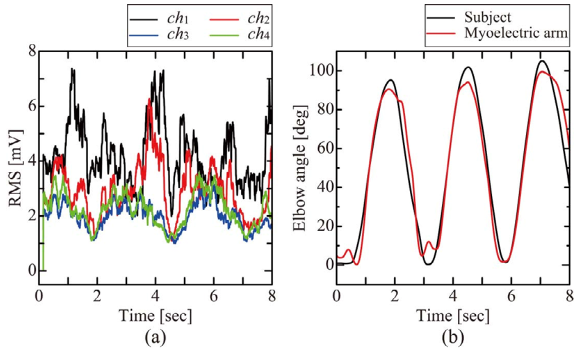


Fig. 4 Experimental condition.



(a) (b)

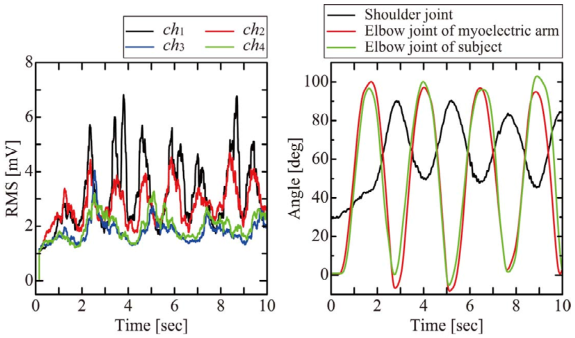
Fig. 5 Experimental result when shoulder joint angle is 0 degree.



(a) (b)

Fig. 6 Experimental result when shoulder joint angle is 90 degrees.

Second, the subjects performed the cooperative motion of the shoulder and elbow joint. The experimental result is shown in Figs. 7 and 8. Figure 7 shows the RMS values of EMG signals and shoulder and elbow joint angles. Figure 8 shows the hand position of the subject A. The origin is the shoulder joint and the direction of each axis in Fig. 8 is shown in Fig. 4. The blue line in Fig. 8 shows the initial posture of



(a) (b)

Fig. 7 Experimental result during concerted motion.

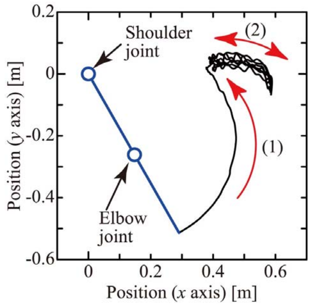


Fig. 8 Hand position during concerted motion.

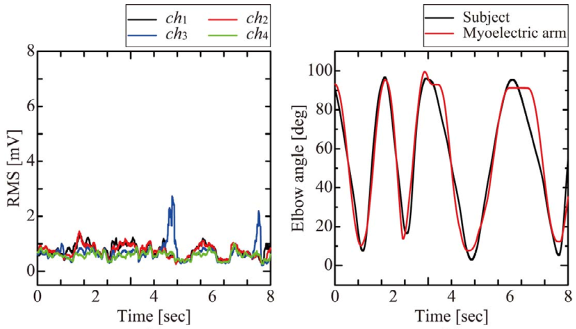
the subject's upper-limb. In the experiment, the subject flexed the elbow joint from the initial posture. After that the subject moved the hand back and forth. As shown in Fig. 7(b), the myoelectric arm could follow the subject's motion even though the shoulder joint of the subject moved dynamically at the same time. Similar results were obtained with the subjects B and C.

Figures 9 and 10 show the experimental results of subject B and C, respectively. From Figs. 9 and 10, one can see that the myoelectric arm could follow the subject's motion, even when the velocity of the motion was changed or both of the biceps brachii and the triceps brachii were activated.

These experimental results show that the proposed controller could realize the proper elbow motion of the myoelectric arm considering the influence of the shoulder joint motion on EMG signals.

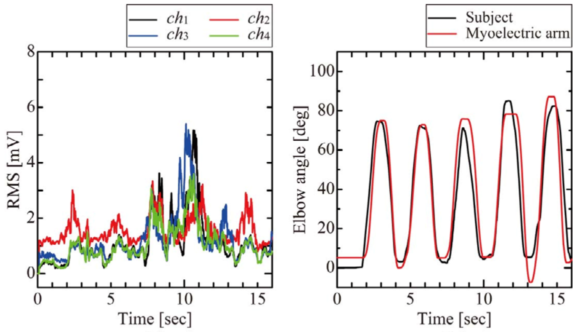
V. CONCLUSIONS

In this paper, the control method of the elbow motion of a myoelectric arm for above elbow amputees is proposed. In the myoelectric arm, the EMG signals of the biceps brachii and the triceps brachii muscles are used as input. Since these muscles are the biarticular muscles between the shoulder joint and elbow joint, the amount of the EMG signals of these muscles are changed depending on the motion of the shoulder joint. In the proposed control method, the influence of the shoulder joint motion on EMG signals of these muscles is removed using the neuro-fuzzy modifier in order to realize proper elbow motion. The experimental results showed the effectiveness of the proposed method.



(a) (b)

Fig. 9 Experimental result when the velocity of the motion was changed.



(a) (b)

Fig. 10 Experimental result when antagonistic muscles were activated.

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