Proceedings of the SICE Annual Conference 2018
September 11-14, 2018, Nara, Japan

Reset operation accompanying parameter adjustment in CG hand manipulation by EMG signals

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Abstract: This paper aims at applying EMG signals as one of the promising interfaces to the intelligent machines. As an example of the robotic interface, we here consider an operation problem of a CG (computer graphics) hand in a PC monitor by means of EMG signals. The purpose of the CG hand control is to track the target hand motion overlaid on the monitor using EMG, but the long-term operation produces the increasing error due to its accumulation. This paper discusses a recovery process from such an increasing error. As a solution, a reset operation that accompanies parameter adjustments of the muscle dynamics producing the CG hand motions is newly introduced. The parameter adjustment are derived from the following criterion: Reduce the error at the reset operation, if exactly the same EMG signals are inputted from the same initial condition as previous reset operation. Some experiments in the ideal conditions demonstrated the convergence of the error by the repetition of the reset operation with the parameter adjustment, though the actual application not satisfying the conditions produced the error.

Keywords: EMG, motion control, signal processing, reset operation, parameter adjustment

1. INTRODUCTION

Humans produce their intended movements to achieve some requirements for the daily life by handling many joints and segments. Such complex and purposeful movements of humans are controlled using the bio-signals that nerves system generated. Therefore, the human motional intention might be directly detected with the analysis of the bio-signals, i.e., another possible communication interface different from one being based on the language, touch-panel or mechanical switches.

An EMG (electromyographic) signal is one of the bio-signals that reach muscles and trigger their contraction. Thus, the human motion intention can be detectable from the EMG signals: the command to control the multi-DoF robot hands might be controllable as intended by processing many channels of EMG signals from the forearm.

For this purpose, we are studying surface-EMG (henceforth EMG denotes surface EMG) to detect the hand movement. Many approaches to motion detection from the EMG are proposed [1, 2]. As mentioned in the following section, a characteristic of our approach is found in the attachment of the electrodes allowing some deviations from the precise position of agonists though multiple numbers of electrodes are required. Such an approach are found in [3-5]. However, no-error estimation or control have been almost impossible in our framework using the EMG, due to the difficulty in modeling the EMG dynamics, or its parameter variations during the operations: this implies that preparing the recovery process from an error-generating situation is more realistic for the application of the EMG control. From this point of view, we discuss the recovery process in the framework of a CG (computer graphic) hand control using EMG signal.

† Satoshi Ito is the presenter of this paper.

2. PROBLEM FORMULATION

2.1. Situation in consideration

We consider a situation where an operator has to manipulate a robot hand in a master-slave manner using its own hand. The operator can observe the robot motion without delay, and thus can correct the robot hand movement after checking the result. The sensors for detecting the operator motion are basically restricted to several electrodes of EMG signals: any other motion sensors such as angular sensors or camera measurement systems are not in use. Our purpose is to construct the controller for the robot hand based on the measurement of the operator's EMG signal so that the robot hand moves as the operator intended.

For the above situation, we set the following conditions to make the problem manageable:

- Instead of the robot hand, the operator manipulates the CG hand drawn by the computer graphics in the monitor.
- Only the wrist motion in the right hand is considered. The motions of the fingers and thumb are not treated in this paper.
- The desired motion of the CG hand is translucently overlaid upon the one that the operator is actually manipulating.

Here, we have some comments on the third conditions. To evaluate the controller we construct, some criteria are required. We considered one of the important criteria is the positional error in the hand movement. In the master-

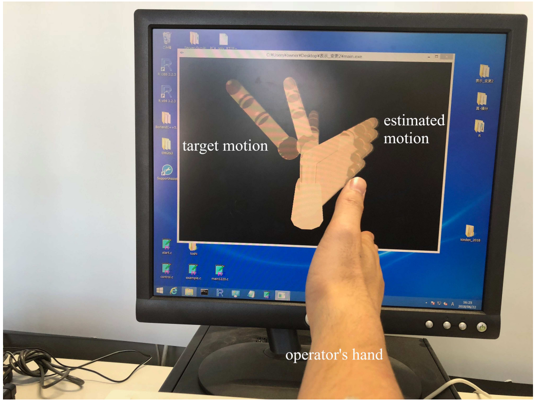


Fig. 1 CG hand and its overlaid target posture.

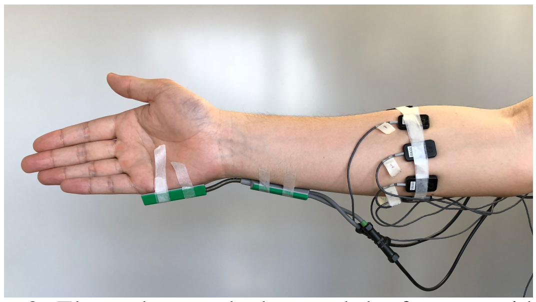


Fig. 2 Electrodes attached around the forearm with the same intervals.

slave control, the hand motion is completely depend on the operators intention. There, the positional error is expressed as the difference between the actual hand position and the one the operator intended. However, the operator's intention is undetectable in general. This is a reason why we introduced the desired hand motion. Here, we instruct the operator to control the CG hand to follow the target hand overlaid. This instruction will make the operator attempt to match the manipulating CG hand to the overlaid one denoting the desired motion: Namely, the target hand can be regarded as the motion the operator intended. Based on this scenario, we will evaluate the position error as the difference between the manipulating CG hand and the target one throughout this paper.

2.2. Problems to solve

Under the above situation, we conducted the manipulation of the CG hand using EMG signal by means of the method in the section 3. Although the primal requirement is to reduce the positional error, we found, from the several preliminary experiments, that no-error control were almost impossible even in the one DoF motion of the wrist since the target hand were always moving. In addition, once the error occurred, it does not tend to reduce afterward, because the error is basically caused from the inadequacy of the dynamical model for producing the CG hand motion.

From these results, we have gotten the following idea: the preparation to the error occurrence will be more effective and realistic than its prevention. Thus, in this paper, we consider the following recovery problem after the error is produced during the manipulation of the CG hand.

Recovery problem: What is an effective method to continue the manipulation of the CG hand by the EMG signals even when the error happens during the manipulation?

2.3. Solutions

As the recovery from the error generation, we firstly introduce the reset operation. The reset operation forces the CG hand take the same posture as the target hand representing the desired motion. The reset operation should not be always working: it must act only at the timing when the operator requires it. Therefore, we will prepare an interface to trigger it.

The reset operation will certainly zero the error once. However, the continuance of the manipulation will produce the error again in the same way as the manipulation so far. Of course, the error may decrease because the operator gets familiarized with the manipulation and learns a better manner. But, if there are no improvement for the EMG controller of the CG hand, the error reduction stops when the operator's familiarization stops.

Thus, we will next introduce the controller improvement, i.e., the parameter adjustment of the EMG controller. This adjustment will be conducted based on a amount of the error at the reset operation. Namely, it changes the coefficients of the dynamics inside the controller so that the error will decrease at the next reset operation, if the same EMG signals are inputted.

3. FORMULATIONS

3.1. Feature of our controller based on EMG signal

We have already constructed the controller based on the EMG signals. Then, the following problems arose.

Anatomical knowledge A utilization of EMG signals requires some anatomical knowledge on muscles, because the suitable attachment of the EMG electrodes brings the better signal detection.

Noise and cross-talk Weak EMG signals are easily affected from the noise even by small fluctuations of the electric cables. In addition, the electrode attached on the surface of the skin essentially contains other signals than the agonist, causing cross-talks.

Dynamical model The classification of the hand motion is another framework using the EMG signals. The tracking control of the CG hand to the target hand here is different from the classification and has to produce the smooth and continuous motion, which requires a dynamical model where the EMG signals are inputs and the joint angles are outputs.

Regarding the first problem, the detection of the complex hand motion needs the attachment of many electrodes. Actually, it took about one hour for us to paste eight electrodes on the fore-arm for the first time. The difficulty in attaching the electrodes will prevent EMG signals from spreading as an convenient interface. To solve this problem, we adopted a method to attach multiple numbers of electrodes around the forearm with the same intervals: eight electrodes were aligned and stuck on one band, which were rolled up around the fore-arm to detect the EMG signal as shown in Fig. 2.

This pasting method, however, usually places the electrodes at the different position from the agonist of the target motion. This was why we introduced a component analysis of multi-channel EMG signals: using this signal processing, we attempt to pick up the agonist EMG component. This processing is expected to simultaneously solve the second problem, noise and cross-talk.

As for the third problem, the muscle dynamics was introduced to estimate the joint angle deviation from the EMG components. This dynamics is expected to provide the continuous translation from the muscle activities to the hand movements.

In short, our method is featured by the following three, "electrode band", "signal component analysis" and "muscle dynamics".

3.2. Muscle dynamics

The linear model of the muscle dynamics is introduced to generate the wrist motion using EMG signal.

$$I\ddot{\theta} + B_m\dot{\theta} + K_m(\theta - \theta_0) = u_e - u_f \tag{1}$$

Here, θ is the deviation of the wrist, I is the inertial moment of the wrist, B_m and K_m are the viscosity and elasticity of the joint affected by the muscle property, respectively, and θ_0 is the angle when the muscles are in the natural length. u_e and u_f denote the muscle activities of the extensor and flexor of the wrist joint, respectively, that are estimated through the Principal Component Analysis from eight EMG signals: the first and second principal component of the EMG data measured in advance during the sole repetitions of the wrist extension-flexion are utilized as u_e and u_f.

Discretizing (1) from the next relations,

$$\dot{\theta} = (\theta(k) - \theta(k-1))/\Delta T \tag{2}$$

$$\ddot{\theta} = (\theta(k+1) - 2\theta(k) + \theta(k-1))/(\Delta T)^2 \tag{3}$$

we can obtain the following difference equation containing the bias component:

$$X_{k+1} = AX_k + BU_k \tag{4}$$

where

$$X_k = \begin{bmatrix} \theta(k-1) \\ \theta(k) \end{bmatrix}, U_k = \begin{bmatrix} u_e(k) \\ u_f(k) \\ 1 \end{bmatrix}, \tag{5}$$

$$A = \begin{bmatrix} 0 & 1 \\ A_{21} & A_{22} \end{bmatrix}, B = \begin{bmatrix} 0 & 0 & 0 \\ B_{21} & B_{22} & B_{23} \end{bmatrix} \tag{6}$$

$$A_{21} = (2I - B_m\Delta T - K_m\Delta T^2)/I \tag{7}$$

$$A_{22} = (-I + B_m\Delta T)/I \tag{8}$$

$$B_{21} = \Delta T^2 \tag{9}$$

$$B_{22} = -\Delta T^2 \tag{10}$$

$$B_{23} = K\Delta T^2\theta_0 \tag{11}$$

Namely, the wrist angle at the discrete time $k+1$ is calculated from that at the discrete time k and $k-1$ as well as the muscle activities at the discrete time k.

3.3. Parameter adjustment

3.3.1. Criterion

To discuss the parameter adjustment of muscle dynamics, suppose that the posture, in other words, the joint angle generation from this dynamics, is reset at the discrete time n.

At the moment of the reset operation, the posture of the CG hand the operator controlling jumps, i.e., abruptly changes, to that of the target hand: the amount of this jump is called here error. We can detect this error as the difference between the manipulating and the target hands.

Based on the error, we update the parameter of the dynamics. The criterion of the parameter update is defined as follows:

Criterion of parameter update: Update the parameters of the muscle dynamics in order to decrease error at the discrete time n if exactly the same EMG signals are inputted again from exactly the same initial state of the previous reset operation.

3.3.2. Mathematics

We define the error between the manipulating hand and the overlaid target hand at the discrete time n as

$$e_n = X_n - X_n^d \tag{12}$$

and, the cost function to minimize as

$$V = \frac{1}{2}e_n^2. \tag{13}$$

The parameters of the muscle dynamics, A and B are updated so as to decrease this cost function.

$$A \leftarrow A - k\frac{\partial V}{\partial A} \tag{14}$$

$$B \leftarrow B - k\frac{\partial V}{\partial B} \tag{15}$$

These updates require the calculation of the derivatives of V. They are given as follows.

$$\frac{\partial V}{\partial A} = e_n \cdot \frac{\partial e_n}{\partial A} = e_n \cdot \frac{\partial X_n}{\partial A} \tag{16}$$

$$\frac{\partial V}{\partial B} = e_n \cdot \frac{\partial e_n}{\partial B} = e_n \cdot \frac{\partial X_n}{\partial B} \tag{17}$$

Here, we show that both $\frac{\partial X_n}{\partial A}$ and $\frac{\partial X_n}{\partial B}$ are computed in a recursive manner. Actually, differentiating (4) with respect to a and B, the following recurrence relation:

$$\frac{\partial X_k}{\partial A} = A\frac{\partial X_{k-1}}{\partial A} + \frac{\partial A}{\partial A}X_{k-1} \tag{18}$$

and

$$\frac{\partial X_k}{\partial B} = A\frac{\partial X_{k-1}}{\partial B} + \frac{\partial B}{\partial B}U_{k-1} \tag{19}$$

Namely, $\frac{\partial X_k}{\partial A}$ and $\frac{\partial X_k}{\partial B}$ are obtained from those at the previous discrete time $k-1$ as well as X_{k-1} and U_{k-1}.

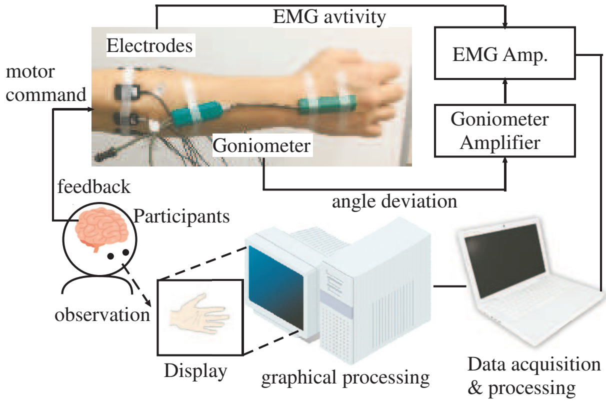


Fig. 3 Experimental setups.

3.3.3. Algorithm

The parameter adjustment is summarized as the following algorithm:

Algorithm for parameter adjustment :

STEP 0 Reset $k = 0$, and reset the CG hand to take the same posture as the target hand, i.e., $X_0 = X_0^d$.

STEP 1 Wait in the control period T.

STEP 2 Increment k, and update the target posture X_k^d.

STEP 3 Detect the EMG signals from all the electrodes, and the calculate U_k, the muscle activity of the agonist/antagonist of the target motion using the PCA.

STEP 4 Move the CG hand to X_{k+1} using the muscle dynamics (4).

STEP 5 Update $\frac{\partial X_k}{\partial A}$ and $\frac{\partial X_k}{\partial B}$ by (18) and (19), respectively.

STEP 6 If the reset operation are not being invoked, go back to to STEP 1 and repeat the steps again.

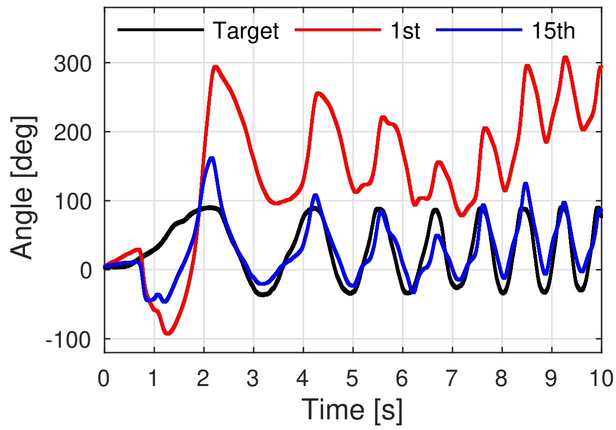
STEP 7 Adjust A and B by (14) and (15), respectively, and then return to STEP 0.

4. EXPERIMENTS AND RESULTS

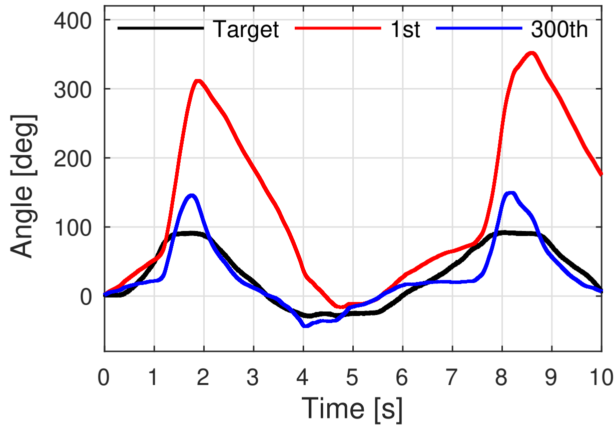
4.1. Purposes and Setup

Two experiments are conducted: The first experiment confirms the convergence of the above algorithm under the situation where all the assumed conditions hold. The second one evaluates the performance of the above algorithm when it is applied to the realtime control where the operator controls the CG hand using their EMG with observing the CG hand itself as well as the target hand.

The experimental setup is illustrated in Fig. 3. Eight electrodes are pasted around the upper parts of the participant's forearm in almost the same intervals. At the same time, the goniometer was attached to detect the actual wrist angle deviation that is utilized to estimate the initial parameters values in the dynamics. The experiments were conducted in the relax condition: During the experiments the operator was seated on the stool and was asked to place the elbow on the desk with bending it in comfortable amount.



(a) pattern 1



(b) pattern2

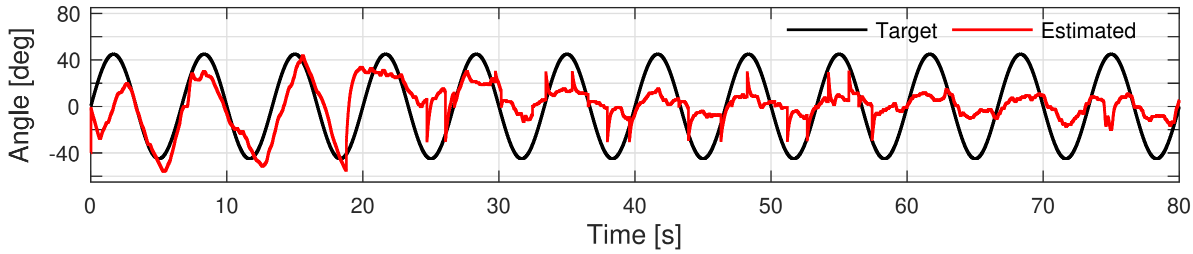
Fig. 4 Convergence experiment.

The signal of the goniometer is amplified by the amplifier for its own, and sent to the computer as the voltage signal together with the EMG signal. The A/D converter card acquires those signals in 2.5kHz. The wrist angle deviation is obtained by the linear relationship between the angle deviation and the output voltage of the goniometer. On the other hand, the EMG signals are filtered by the 4.8Hz second-order Butterworth filter and next rectified by the EMG amplifier: The rectified EMG signals are processed using the PCA and the two components, the extensor and the flexor, are extracted. Then, the wrist motion is generated through the dynamical model in section 3. The generated angle value is sent to the computer for display every 10 control cycles.

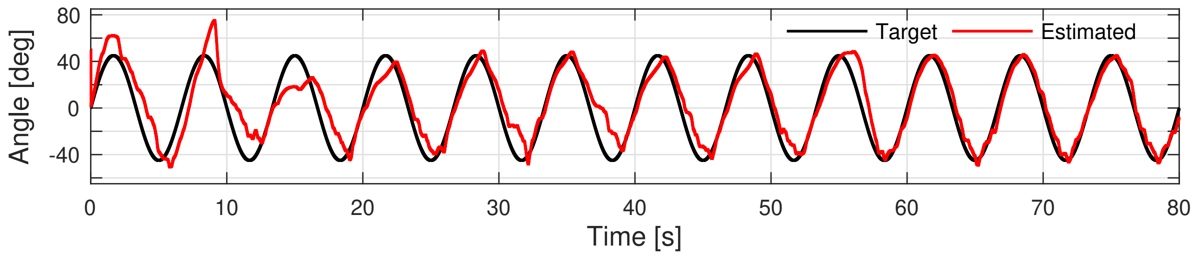
Only the extension-flexion of the wrist is considered throughout the experiments. One of the authors (24 year-old, male) conducted the experiment as an operator.

4.2. Convergence experiment

The algorithm in section 3.3.3 is defined to reduce the error at the discrete time n under the condition that the same EMG signals are input again from the same initial state as the previous reset operation. The aim of this experiment is to confirm that this algorithm certainly reduce



(a) experiment with reset operation at 0 deg and ±30 deg.



(b) experiment only apply the parameter adjustment.

Fig. 5 Realtime control experiment.

the error e_n under this condition by its repetitive application.

The two target motions are selected as follows:

$$\theta_d = \Theta \sin(\omega_0 t), \omega_0 = \pi t/20 \quad (20)$$

for the pattern 1, and

$$\theta_d = \Theta \sin \omega_1 t, \omega_1 = 2.961 \quad (21)$$

for the pattern 2. In both cases, Θ was set to 45deg. This target motion was presented to the operator as the overlaid animation of the target hand on the monitor,

During 10s experiments, we instructed the operator to control the CG hand to take the same posture as the target hand. The time course of the CG hand that the operator manipulated based on (1) is depicted in red in Fig. 4, while the time course of the actual hand motion detected from goniometer is depicted in black: the upper graph denotes for the pattern 1 and the lower one denotes for the pattern 2. These graphs indicate that, although the operator tried to coincide the CG hand posture to the target one, two hands differed largely.

Next, the parameter adjustment was applied with the reset operation at 10s: After the parameter update (14) and (15), the wrist angle is set to the initial position and the SAME 10s EMG signals (we do not have to measure them. Just reuse the previous one.) were inputted to the dynamics (1) or (4) again. Then, the error (12) after the parameter adjustment was obtained, which can be used to parameter adjustment again. The repetition of the above parameter adjustment and the reset operation changes the time course of the wrist angle the dynamics generates, as depicted in blue in Fig. 4: The calculation result (blue) coincided the target angle (black) at 10s as expected, after 15-times repetition for the pattern 1, and 300-times repetition for the pattern 2.

These experiments demonstrate that the algorithm in the section 3.3.3 makes the error at the reset operation decrease, if the same EMG signals are applied again from the same initial state to the same reset time.

4.3. Realtime control experiment

In the next experiment, this algorithm is applied to the realtime control of the CG hand. The reset operation is incorporated to be triggered by hitting the designated key of the PC keyboard. The duration of the experiments is 80s. The first 10s and last 20s are devoted to the normal operation without reset operation, while the reset operations as well as the parameter adjustments are executed at several times in 10s to 60s. The effect of the parameter adjustments will be evaluated by comparing the performance between first 10s and last 20s.

In the first experiment, the operator was asked to push the reset key whenever the angle of the CG hand approached zero or ±30deg. The time course of the CG hand angle is depicted with its target angle in Fig. 5(a). Unfortunately, the comparison of the performance before and after the reset operation with parameter adjustment does not represent any remarkable improvements in the accuracy, i.e., the smallness of the error: The parameter adjustment seems only to decrease the amplitude of the CG hand motion monotonically.

The experiments in the previous section demonstrated that the error convergence requires several tens of the parameter adjustment. Thus, in the next experiment, we tried to apply the parameter adjustment automatically in the short intervals without reset operation, i.e., not execute any reset operations but only execute the paraleter adjustments. The time course of the CG hand angle then is depicted together with its target angle in Fig. 5(b). Although the large error was observed in the first 10s, the errors have gotten small after parameter adjustment. This relatively good result may give us some hints to construct the EMG controller in our future works.

5. CONCLUDING REMARKS

This paper considered the EMG manipulation of the CG hand displayed on the PC monitor. Its purpose is to control the CG-hand so as to dynamically track the target hand motion translucently overlaid on it. A feature of our system is found in the attachment of the EMG electrode which are pasted around the forearm with the same intervals. Then, the muscle activities of the agonist for the target motion are estimated using the primary component analysis. A dynamical model is introduced to produce the CG hand motion from the estimated muscle activities.

In the actual application of this system, however, the CG hand certainly deviated from the target motion due to the accumulation of the errors. Therefore, in this paper, we newly introduced the reset operation that accompanies the parameter adjustment of the muscle dynamics producing the CG hand motions. The formulation of the parameter adjustment were derived from the following criterion: the error is getting small with the repetitive parameter adjustment if the same EMG signals are inputted again and again from the same initial condition after the reset operation. Experiments demonstrated that this reset operation with the parameter adjustment worked under ideal conditions as expected. However, this method could not reduce the error when applying it to the realtime control. There is still a room to discuss the strategy of the reset operation execution to improve the performance in the future works.

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