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THE IMPEDANCE AND POSITION CONTROL OF THE ROBOT MANIPULATOR BY THE EMG SIGNAL

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Abstract − The present paper proposes a human interface regulating the viscoelastic characteristics of the robot manipulator by the EMG signals picked up from the subject. The desired trajectory intended by the subject is generated through the bilinear internal arm model with the EMG input signals, and then the viscoelastic coefficients of robot manipulator are regulated corresponding to the sum of the flexor and extensor EMG levels. It is then shown that the subject is able to change the interactive characteristics against the robot's environment by his own intention.

Keywords: EMG, Impedance control, manipulator

1. Introduction

The present paper pays attention to EMG (Electromyogram) signal to obtain the inner information of human motion. The EMG includes the important information on the motion patterns, the muscle forces and viscoelastic levels. Until now, the EMG signal has been used to control the prosthetic hand. Though several methods are proposed, for example, the motion intended by the amputee, such as flexion, extension, pronation, supination, grasping and hand-opening, is controlled by the surface EMG signals measured from a part of the muscles which have actuated the original limb. At first, the neural network with the EMG input signals is trained using both the intended motion and the measured EMG signal, and the neural network after learning gives a particular motion with the highest probability of six ones through the real time EMG signal [1], [2].

Also, the EMG signal is utilized to control a pointing device on the TV screen. A priori probability of each reference direction is estimated through the neural network. The moving direction is assigned by a weighted combination of reference directions. Then, the EMG is, however, used only to estimate one of pre-assigned motion patterns [3].

On the other hand, Koike et al [4] tried to reproduce three dimensional motion trajectories of the upper arm through the neural network with the EMG input signals, by which the virtual arm on the TV screen was controlled.

Now, in daily life, we can regulate the mechanical impedance of our arm or hand skillfully for the various tasks [5], [6]. When we want to squash the fruit with both hands,

we make the arms stiff. When we handle the beautiful clothing carefully, we make the hand soft. Further, we regulate the arm impedance in advance of the physical contact by predicting the task flow and environmental change. For example, when we want to hit a ball powerfully, we take a stiff stance in advance, and inversely when we want to catch a ball with soft touch, the hand and arm impedance will be preset low [7].

Therefore, it is of worth to develop the input device of human-machine interface that can regulate the mechanical impedance voluntarily. For example, Yamakita et al [8] proposed a bi-lateral master-slave system which could regulate the slave impedance in proportion to the grip force of master arm and it was demonstrated that the task was easier of accomplishment than no impedance regulation.

The present paper proposes a new human interface regulating both the viscoelastic characteristics and the motion of the robot manipulator by the EMG signals picked up from the subject. The desired trajectory intended by the subject is generated through the bilinear internal arm model with the EMG input signals, and then the viscoelastic coefficients of robot manipulator are regulated corresponding to the sum of the flexor and extensor EMG levels. It is then shown that the subject is able to change the interactive characteristics against the robot's environment by his own intention and so to cope effectively with the task or environment changes.

2. EMG based Interface

2.1 System block diagram

The overall block diagram of EMG based interface is shown in **Fig.1**, which is consisted of the arm model to estimate an intended arm trajectory from the EMG signal of the human operator and the feedback controller to control the robot manipulator. The latter also includes the hand impedance adjustment based on the EMG signal. The human operator controls the hand trajectory of manipulator based on his own EMG level using the visual information moment by moment.

2.2 Arm model

The arm dynamics is approximated by the second-order system. As previously mentioned, the viscoelastic properties of arm are not constant but variable in proportion to the
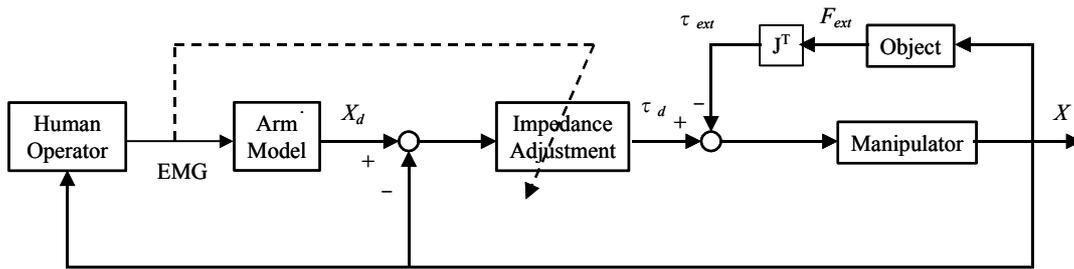
Fig.1 Overall block diagram of EMG based interface

activation levels of arm muscles. It is reported that these dynamic characteristics of muscle contraction is represented by the bilinear model, which shows that the viscoelastic properties of muscle depends on the sum of flexor and extensor muscle contraction levels as follows [5][9].

$$M_h \ddot{\theta} + (B_h + b(\alpha_e + \alpha_f))\dot{\theta} + (K_h + k(\alpha_e + \alpha_f))\theta = \tau \qquad (1)$$

where, θ is the joint angle, τ is the joint torque, M_h, B_h, K_h are the inertia, viscosity, stiffness of human arm, respectively, and b and k are constant coefficients. In addition, α_f and α_e are the contraction levels of flexor and extensor muscles.

The joint torque τ is estimated based on the difference between the flexor and extensor muscle levels as follows.

$$\tau = c\,(\alpha_f - \alpha_e) \qquad (2)$$

where c is the gain constant. By inserting α_f and α_e obtained from the EMG signals of human operator into (1) and (2), we obtain the joint angle trajectory $\theta(t)$. Then the hand trajectory is estimated by transforming it into the hand coordinates.

However, when the EMG levels of human operator become same or 0, the joint torque becomes 0 from (2), and then it is known that the joint trajectory turns back to the equilibrium point. This means that the human operator is unable to keep an intended arm posture. To avoid it, we set a threshold for the joint angle velocity. When the joint angle velocity comes under the threshold, the joint is stopped and then the joint angle at the moment is set to new equilibrium point.
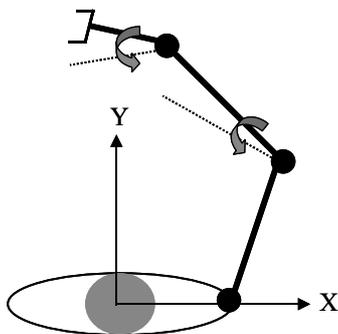

Fig.2 Stick picture on the TV screen

2.3 Joint impedance adjustment

The equation of motion of the manipulator is given by

$$M(\theta)\ddot{\theta} + h(\theta, \dot{\theta}) + D\dot{\theta} = \tau_d + J^T(\theta)F_{ext} \qquad (3)$$

where $M \in R^{m \times m}$ is the inertia matrix, $h \in R^m$ the centrifugal and Coriolis force vector, $D \in R^{m \times m}$ the joint viscosity matrix, and $\tau_d \in R^m$ the joint torque vector, $F_{ext} \in R^l$ the external force and $J \in R^{l \times m}$ the Jacobian matrix.

Now, it is assumed that the desired hand impedance of manipulator is given as follows.

$$M_e d\ddot{X} + B_e d\dot{X} + K_e dX = F_{ext} \qquad (4)$$

where $M_e, B_e, K_e \in R^{l \times l}$ are the desired inertia, viscosity, stiffness matrices of manipulator hand, respectively, and $dX = X_e - X_d$ represents the deviation between the present hand position and the desired one.

Then, the joint torque τ_d required to realize the desired hand impedance (4) is given by

$$\begin{aligned} \tau_d = J^T (JM^{-1}(\theta)J^T [M_e^{-1}(-K_e dX - B_e d\dot{X} \\ + F_{ext})K_e - \dot{J}\dot{\theta} + d\ddot{X}] + h(\theta, \dot{\theta}) + D\dot{\theta} - J^T F_{ext} \end{aligned} \qquad (5)$$

where B_e and K_e are determined from the EMG level of human operator as shown in Fig.1.

3. Experiments

3.1 EMG signal processing

The L channels EMG signals measured on the skin surface was A/D converted with the sampling frequency of 1 KHz and after full-wave rectified, it was smoothed through the low-pass second-order Butterworth filters (Cut-off frequency: 1 Hz). Then each of the EMG signals was normalized by the maximum contraction level of the corresponding muscle as follows.
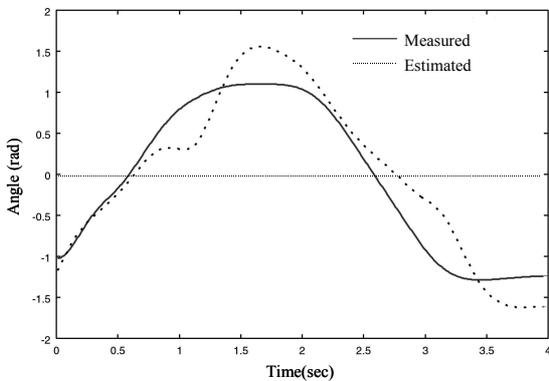
$$X(j) = \frac{EMG(j) - EMG_{thr}(j)}{EMG_{max}(j) - EMG_{thr}(j)} \quad (j = 1, \cdots, L) \qquad (6)$$
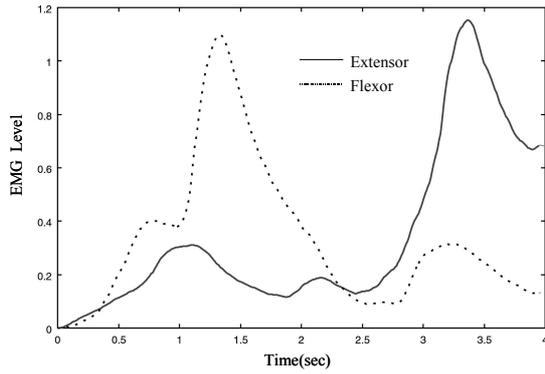
(a) Flexor and extensor filtered EMG signals
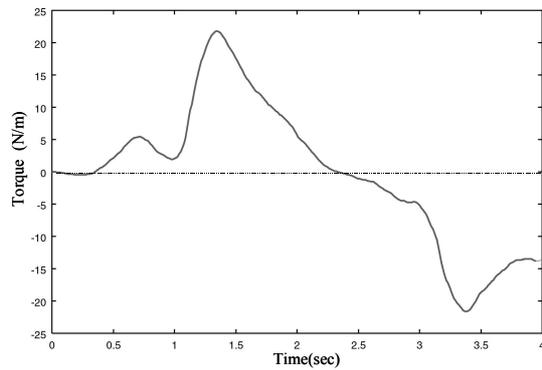
(b) Joint torque estimated from EMG signals

(c) Measured and estimated joint angles
Fig.3 Elbow joint motion

picture as shown in **Fig.2**. The arm motion of the human operator was limited on two dimensional plane. The EMG
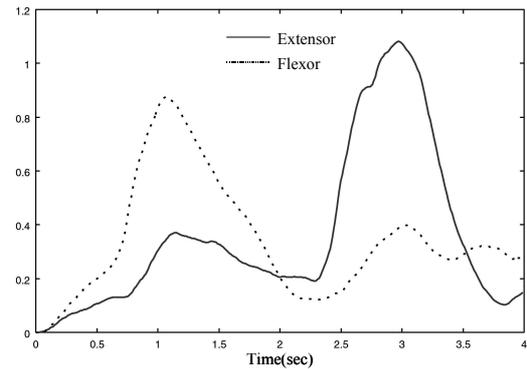
(a) Flexor and extensor filtered EMG signals
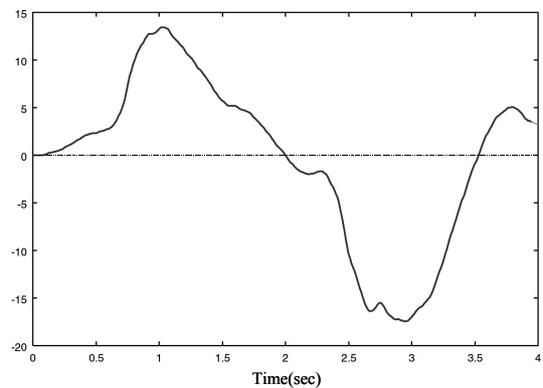
(b) Joint torque estimated from EMG signals
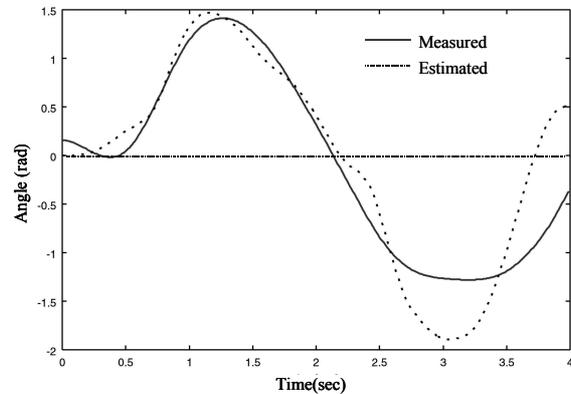
(c) Measured and estimated joint angles
Fig.4 Wrist joint motion

signals are generated by the flexion and extension, sometimes co-contraction of the wrist and elbow joints. Four pairs of surface electrodes (L=4) were attached on flexor (capri radialis) and extensor (capri ulnaris) of the wrist joint, and flexor (biceps brachii) and extensor (triceps brachii) of the elbow joint.

where $EMG_{max}(j)$ is the EMG level at the maximum contraction force, and j=1,2 denotes the wrist joint muscles and j=3,4 elbow joint muscles. Since each $X(j)$ (j=1,2 or 3,4) correspond to α_{if} and α_{ie}, the joint torque is obtained from (2) as follows.

$$\tau_i = c_i(\alpha_{if} - \alpha_{ie}) \qquad (i=1,2) \qquad (7)$$

3.2 Experimental set up

The subject was asked to follow a desired motion displayed as the stick picture on the TV screen. The output motion of manipulator was displayed by another stick

3.3 Trajectory generation by the arm model

At first, some experiments were done to verify whether it is possible to reproduce the arm movement correctly through the arm model from the EMG signals, about the wrist and elbow joints respectively. The subject was asked

to rotate his wrist or elbow joint freely and randomly. Then the rotation angle of the joint was measured by the goniometer and at the same time the EMG signals were measured.

The arm trajectory estimated through the arm model was displayed on the CRT screen simultaneously. So the subject can regulate the EMG level by watching it. **Fig.3** and **4** shows (a) the flexor (dotted line) and extensor (solid line) filtered EMG signals, (b) the joint torque estimated from EMG, and (c) the measured (solid line) and estimated (dotted line) joint angles, respectively. It is confirmed that the arm model can reproduce the joint motion within the reasonable error.

3.4 Manipulation tasks

Next few manipulation tasks were performed. Both dynamics of the manipulator and ball are simulated on the computer. Then the motions of ball and arm are displayed on the TV screen on real time. The task is to hit the ball back rolled on the floor with friction and stop it at a desired position. Therefore, the subject is required to control the joint motion of manipulator and at the same time the viscoelastic property of the manipulator joint using only his EMG signals.

The interaction force between the manipulator hand and ball was determined as follows.

$$F_{ext} = \begin{cases} B_b d\dot{X}_b + K_b dX_b & |X_r| \le r \\ 0 & |X_r| > r \end{cases} \quad (8)$$

$$dX_b = X_0 - X_e - R_b n \quad (9)$$

$$n = \frac{X_0 - X_e}{|X_0 - X_e|} \quad (10)$$

where B_b and K_b are the viscosity and stiffness coefficients of ball, R_b the radius of ball, X_0 the position of ball, X_e the hand position of manipulator, provided that when $d\dot{X}_b \cdot n > 0$, $B_b = 0$.

The first experiment is as follows.

Task 1: *Two kinds of mass of ball: M_b =1Kg and 3 Kg. After the first hit for M_b =1Kg, the serial second hit for heavier ball: M_b =3Kg is required for the subject with keeping the same travelling distance as the lighter ball.*

The experiments were done about two cases:
1) The manipulator impedance in (4) is fixed at M_e=1, B_e=30 and K_e=60, which means that the subject cannot change the joint impedance of manipulator.
2) The manipulator impedance in (4) is changed depending on the EMG level of the subject's arm muscles, which means that the subject can adjust the manipulator joint impedance voluntarily. Then the viscosity and stiffness coefficients are determined as follows.
$$K_e = 20 + 60(\alpha_e + \alpha_f)^2$$
$$B_e = 10 + 30(\alpha_e + \alpha_f)^2$$
Then the resultant travelling distances in both cases are shown at **Table 1**.

Table 1 Traveling distances of ball

	Fixed	Variable
M_b =1Kg	3.92 m	5.44 m
M_b =3Kg	0.73 m	4.80 m

When the manipulator impedance is fixed, the subject is impossible to hit the ball back to the same distance as the heavier ball due to the soft joint. On the other hand, in the case of the variable impedance, the subject can chooses suitable impedance depending on the object impedance as follows.

Fig.5 shows the stiffness time score of manipulator in Task 1. In order to realize the same travelling distance, it is seen that the subject keeps larger stiffness for M_b =3 Kg than for M_b =1 Kg. As well known, when we move the heavy object, the joint is kept stiff by making the joint impedance large through the muscle co-contraction. It is seen that the same is realized by the proposed interface.
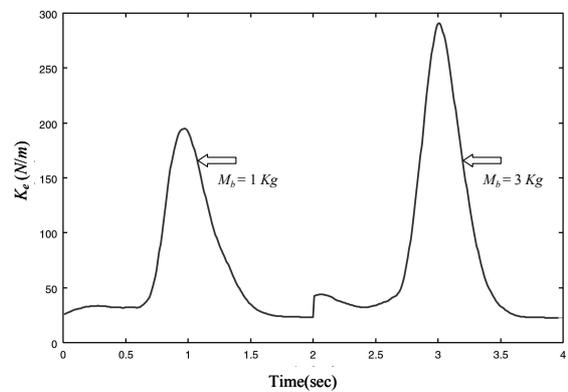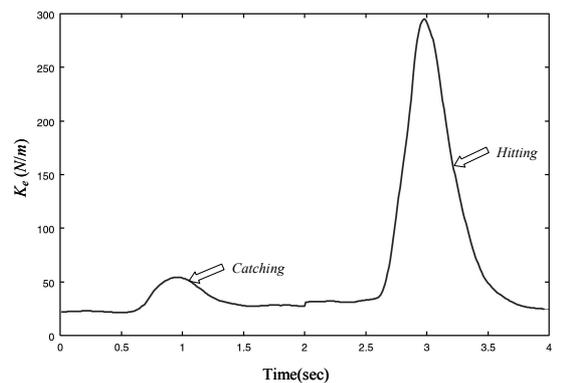

Fig.5 Stiffness of manipulator for Task 1

Fig.6 Stiffness of manipulator for Task 2

Task 2: *Catching and hitting: The subject is required to catch and in serial hit the ball with M_b =1Kg.*

The stiffness time score of manipulator in Task 2 is shown in **Fig.6**. It is seen that the stiffness K_e at the catching is much lower than that at the hitting. This verifies that the EMG controlled interface is effective for the manipulation task interacting dynamically with the object.

4. Conclusion

We proposed the new human interface which was able to regulate both the motion and impedance characteristics of the robot manipulator by the EMG signals of the human operator. Two kinds of manipulation tasks, hitting and catching, were performed on the TV screen. The experimental results verified that the EMG controlled interface is effective for the manipulation tasks interacting dynamically with the object. It will be more effective to use the proposed EMG based interface together with Data-Glove or Motion capture systems that picks up only the external motion of human body.

Acknowledgments

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