Pinpointed Muscle Force Control via Optimizing Human Motion and External Force

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Abstract: The main focus of our research is to control the load of selected muscles by using a power-assisting device, thus enabling more effective motion support, rehabilitation and training by explicitly specifying the target muscles. In our past research, a control method was proposed for static human motion. The results of simulation and experiments showed that it is possible to control the force of selected muscle individually. However, the past method we proposed was only considered for constant posture, which led to a large effect of non-target muscle. In this paper, a new pinpointed muscle force control method is proposed to reduce the effect of non-target muscle taking into account human motion and external force. Human motion and external force was optimized individually in a double-loop searching algorithm, which reduced the computational cost. By calculating the posture step by step, this method can also be used for quasi-static motion. The validity of this method was confirmed by measuring surface EMG signals for each muscle.

Keywords: Musculoskeletal model; Rehabilitation; Training; Human motion generation.

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1 Introduction

Power-assisting system is an important research area of robotics technology for enhancing the mobility of senior citizens and people with disability. Power-assisting device uses the driving force of actuators to support operator's athletic ability (e.g. reduce physical load or increase physical ability), such as for assembly operation and outdoor work. Other potential applications are for muscle rehabilitation and sports training. In biomechanical research area, power-assisting device is also expected to support the load of muscle individually, such as for muscle function diagnostic, muscle force testing and sport training. For example, in clinical medicine, muscle strength assessment is necessary for determining distribution of weakness, disease progression, and/or treatment efficacy (Durfee & Iaizzo 2006). However until now, although its reliability and accuracy are questionable, manual muscle test is the most widely used method to assess muscle function(Clarkson 2000). The assignment of these tests is still based on the clinical judgment and the experience of doctors or therapists, which cannot be tested quantitatively. Therefore, it is hoped to control the muscle force and function by the handy robot devices.

Currently, various power-assisting devices have been developed for supporting the human joint torque in factory and daily life (Kazerooni 1993, Kazerooni et al. 2006, Guizzo & Goldstein 2005, Toth et al. 2004, Lee & Sankai 2002, Kobayashi et al. 2009, Yamamoto et al. 2002). These devices have been confirmed that they are useful for controlling the joint torque and reducing the loads of related muscles by supporting motion. However, rehabilitation and training without effecting uninjured muscle are not so easy , even for the experienced doctor and trainer, due to the complex and the synergistic action of human muscles. For example, the inner muscles, which are hidden deep inside the human body, are difficult to be moved consciously. Many mathematical musculoskeletal models have been developed to investigate the muscle function in more detail (Arnold et al. 2010, Agnesina & Taiar 2006), to the authors' knowledge, there is not a method proposed to plan the rehabilitation or training procedure (e.g. external force, motion/posture), to obtained favorable muscle activation patterns. However it is still difficult to control the muscle force and support a particular muscle due to nonlinear and complex relations among muscles because most of the power-assisting devices can only control the torque of joint.

The main focus of this research is to develop a Pinpointed Muscle Force Control (PMFC) method to control the physical load of selected muscles by using power-assisting device, thus enabling more effective motion support, rehabilitation, and training by explicitly specifying the target muscles. In our past research, we already analyzed the feasibility of the muscle force desired in the PMFC method as a constrained optimization problem, where we take into account the

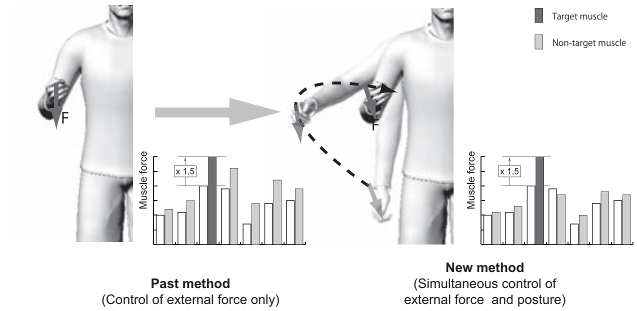


Figure 1 Concept: White boxes show the force of some muscles (X-axis) without control. In both our past method and new method, target muscle can be controlled to desired value (1.5 times, dark gray boxes). However in new method, we want to reduce the change of the force of non-target muscles (light gray boxes) by moving human body and optimizing the external force.

physical interaction between human muscle forces and actuator driving forces during power-assisting device (Ding et al. 2007, 2008). However in our past control method, user's posture was fixed to easy the calculation of the target external driving force, which may also give a large effect on non-target muscle.

In this paper, we proposed a new pinpointed muscle force control method not only to obtain the desired force of target muscle, but also to reduce the effect of other non-target muscles by adding the motion unlike the prior method. As shown in Fig.1, using our new method, the change of the non-target muscle forces are reduced, while the force of the target muscle must keep in the target values. Since there are more parameters (control joint angles and external forces) than before (control external forces only), our past mathematical analysis method cannot be applied. In order to reduce the computational cost, we propose a new searching method, which hierarchically searches the joint angles and external forces. This searching algorithm is tested for both isometric and isotonic exercises (static and dynamic tasks). In the experiments, we measure the surface electromyography (EMG) signals from target and non-target muscles. The validity of this new method and the effects of non-target muscles are confirmed in both simulation and experiments by comparing the change rate of the EMG signals and the estimated muscle force.

2 Method

2.1 Summary

Human body has a large number of muscles and joints. Our human can control the forces of muscles to gain joint torques. These torques can generate output forces from our body (e.g. foot, hand, finger, and so on) to keep or shift the balance with external force to perform some power required task (e.g. walking, pitching, grasping, and

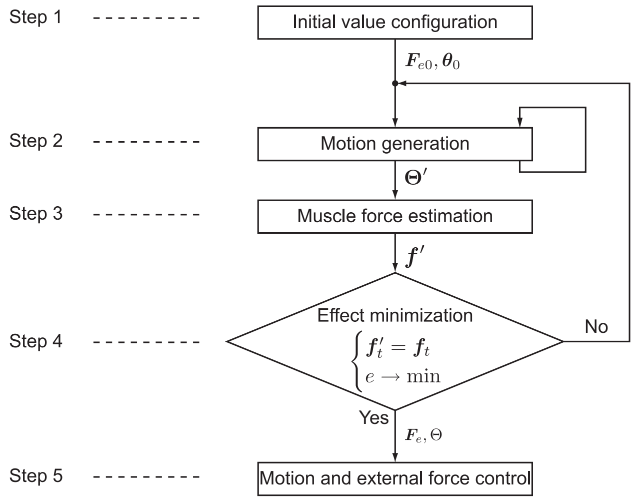
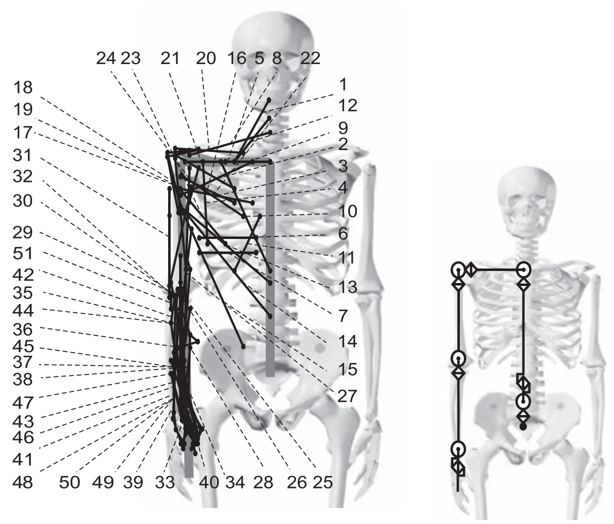


Figure 2 Muscle force control algorithm flowchart: Two-layer searching method. Inner searching loop (STEP 2) is to generate a motion by searching the posture one by one. Outer searching loop (STEP 2-5) is to search a best motion from generated motion in STEP 2.



(a) (b)

Figure 3 Musculoskeletal model . (a)muscle model: 51 muscles in human right upper body were modeled; (b)link and joint model: 12 joints was included in this model.

so on). With the changing of external force, our human can also change the distribution of load acting on muscles without conscious. In this research, our purpose is to search out a set of external force and human motion to change the distribution of muscle forces to realize a desired force on target muscle and do not change the other non-target muscle as much as possible. And in order to complete a task, we also want the basic motion of the target joints will not been changed when we change the muscle force.

However it is almost impossible to do a full search due to the large number of the combination of external force and human motion. In order to reduce the searching time, we developed an effective alternative searching method by searching them individually. A following five-step searching algorithm is proposed to find out this best set of external force and human motion. Figure 2 shows the flowchart of this algorithm. External force is controlled by a robot manipulator or by holding a dumbbell in the hand. Note that, external force is fixed during whole movement because it is still difficult to change and control the force in movement now. And note that, if skip STEP 2 - Motion Generation, this method can also be used for controlling a static motion.

In next chapters, the details of this algorithm will be described.

2.2 Muscle force and human motion(STEP 1)

In our research, a detailed human musculoskeletal model was developed to improve the accuracy of muscle force control (Ueda et al. 2006). Figure 3 shows the musculoskeletal model in our research, which is used to analyze the kinematic characteristic and estimate the human muscle force. This model consists of 5 rigid links with 12 joints corresponding to the waist, neck, shoulder, elbow, and wrist of human right upper body. The attachment points of muscles (origins and insertions) are determined from anatomical data (Maurel & Thalmann 1999, Komura et al. 1999). The moment arms of the muscles calculated from this model have been evaluated.

Human body has a redundant number of muscles N than the number of joints M, which makes the estimation of muscle forces $\boldsymbol{f} = [f_1, \cdots, f_N]^T \in \boldsymbol{R}^N$ from joint torques $\boldsymbol{\tau}_h \in \boldsymbol{R}^M$ an ill-posed problem. In this research, Crowninshield's cost function (Crowninshield & Brand 1981) is used to solve this problem by minimizing a physiologically based criterion $u(\boldsymbol{f})$ as follows:

$$\min \quad u(\boldsymbol{f}) = \sum_{j=1}^{N} \left(\frac{f_j}{S_j} \right)^r \tag{1}$$

$$\text{s.t.:} \quad \begin{cases} \boldsymbol{\tau}_h = \boldsymbol{A}_{(\boldsymbol{\theta})} \ \boldsymbol{f}; \\ f_{\min j} \leq f_j \leq f_{\max j} \ {}_{(j=1,\cdots,N)}, \end{cases}$$

where $u(\boldsymbol{f})$ is the cost function. $\boldsymbol{A}$ is the moment arm matrix of all muscles which is calculated from the joint angle $\boldsymbol{\theta}$ by using our musculoskeletal model. S_j is the physiological cross sectional area (PCSA), and $f_{\max j} = \varepsilon S_j$ is the maximum muscle force for muscle j. $\varepsilon = 0.7 \times 10^6 [\mathrm{N/m^2}]$ was given by Karlsson (Karlsson & Peterson 1991) and S_j was found in (MotCo project 2010). $f_{\min j} = 0, \forall j$ is used. A quadratic cost function, i.e. $r = 2$, is used for simplicity.

In most muscle rehabilitation and training, the move speed of human body is not so fast. Therefore, we defined the human motion $\boldsymbol{\Theta}$ as a discrete change of joint angles at a small interval. It can apply for static and quasi-static

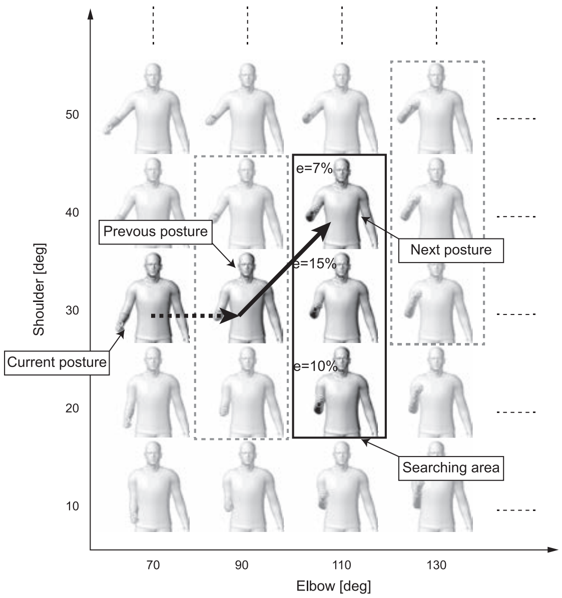


Figure 4 Searching area of next posture. X-axis is the angle change of Elbow joint, which is target joint and has a desired movement. Y-axis is the angle of Shoulder joint. Only next 3 posture nearby the previous posture will be searched.

motion.

$$\boldsymbol{\Theta} = \begin{bmatrix} \boldsymbol{\theta}_1 \\ \vdots \\ \boldsymbol{\theta}_M \end{bmatrix} = \begin{bmatrix} \theta_{10} & \cdots & \theta_{1T} \\ \vdots & \cdots & \vdots \\ \theta_{M0} & \cdots & \theta_{MT} \end{bmatrix}, \quad (2)$$

where θ_{jt} means the angle of joint j at time t. $\boldsymbol{\theta}_j$ is the motion array of joint j from start ($t = 0$) to end ($t = T$), $\boldsymbol{\theta}_j = [\theta_{j0}, \cdots, \theta_{jT}]$; and $\boldsymbol{\theta}_t$ is the array of human posture at time t, $\boldsymbol{\theta}_t = [\theta_{1t}, \cdots, \theta_{Mt}]^T$.

In this first step, we initial values of external force $\boldsymbol{F}_{e0}$ and start posture $\boldsymbol{\theta}_0$ are assigned arbitrarily. The angle of target joint j is start from θ^b_{j0}, ($\theta^b_{j0} \in \boldsymbol{\theta}_0$). Using the above described muscle force estimation method, the initial muscle force $\boldsymbol{f}_0$ can also be obtained. In following searching steps, these values will be changed to close to the optimal values.

2.3 Motion generation (STEP 2)

This step calculates a sub-optimal motion $\boldsymbol{\Theta}'$ for the start posture $\boldsymbol{\theta}_0$ that set in STEP 1. The angle of the target joint is moved following the basic motion θ^b_j and the angles of other joints are searched posture by posture to minimize the change of non-target muscle. Since the motion speed of human is not so fast, only the angles near the previous posture are searched, which reduced the computational cost. At the first time, the start value of external force and posture is $\boldsymbol{F}'_e = \boldsymbol{F}_{e0}, \boldsymbol{\theta}' = \boldsymbol{\theta}_0$, and these values will be changed in STEP 4.

For a slow enough human motion, we only have to search one or two next near postures. Figure 4 shows the searching area of shoulder joint for one next posture. The target joint is elbow joint and the searching area is one right of current posture. The effects of the non-target muscle are calculated for every posture in the search area and the minimum one is selected as next posture. Here, the effect e of non-target muscle at posture θ_i is defined as the change rate of muscle force by comparing with the basic motion.

$$e(\boldsymbol{F}'_e, \theta_i) = \frac{1}{N-1} \sum_{j=1}^{N} \frac{|f'_j - f_{0j}|}{f_{j\max}} \times 100\%$$
$$(j = 1, \cdots, t-1, t+1, N), \quad (3)$$

where $f_{j\max}$ is the maximum muscular exertion force of muscle j. f_{0j} is the muscle force of the posture j in basic motion and f'_j is the muscle force of the searching posture j. The average difference between f'_j and f_{0j} is calculated for all muscles excepting the target muscle ($j \neq t$), which is used as the effect rate e.

By repeating this process posture by posture from the start to the end of basic motion, a suboptimal motion $\boldsymbol{\Theta}'$ can be obtained.

2.4 Muscle force estimation (Step 3)

In this step, the force of each muscle is estimated for each posture using the musculoskeletal model shown in Fig. 3. The integral force $\boldsymbol{f}'$ is used as the muscle force in whole movement.

Integral force of each muscle $\boldsymbol{f}'$ of the searched suboptimal motion $\boldsymbol{\Theta}'$ is calculated as follows:

$$\boldsymbol{f}' = \sum_{i=1}^{T} \boldsymbol{f}'_i, \quad (4)$$

where $\boldsymbol{f}'_i$ is the muscle force of posture i in motion $\boldsymbol{\Theta}'$, which is calculated by our musculoskeletal in (1). The joint torque $\boldsymbol{\tau}_h$ used in (1) is calculated from external force $\boldsymbol{F}'_e$ in dynamics as follows:

$$\boldsymbol{\tau}_h = \boldsymbol{J}(\boldsymbol{\theta}'_i)^T \boldsymbol{F}'_e, \quad (5)$$

where $\boldsymbol{J}$ is the Jacobian matrix of external force $\boldsymbol{F}'_e$ calculated from the joint angle $\boldsymbol{\theta}'_i$; and the moment arm matrix $\boldsymbol{A}$ is also calculated from the joint angle $\boldsymbol{\theta}'_i$ using our musculoskeletal model.

2.5 Effect minimization (Step 4)

Based on the muscle force $\boldsymbol{f}'$ calculated in previous step, the effect rate e of non-target muscle force is calculated. If (a) the desired force of target muscle $\boldsymbol{f}_t$ has not been realized and (b) the effect rate of non-target muscle e has not been minimized, the external force $\boldsymbol{F}'_e$ and the start posture $\boldsymbol{\theta}'_0$ will be reset and return to STEP 2 to calculate again.

These above two conditions (a) and (b) are defined as:

$$\begin{cases} \boldsymbol{f}'_t = \boldsymbol{f}_t \\ e \rightarrow \min \end{cases} \quad (6)$$

where $\boldsymbol{f}_t$ is the desired force of target muscle t, which is calculated from the change rate $\boldsymbol{\gamma}_t$ set by user and the nominal force $\boldsymbol{f}_0$ of basic motion.

$$\boldsymbol{f}_t = \gamma_t \boldsymbol{f}_0 \tag{7}$$

$\boldsymbol{f}'_t$ is the estimated force of target muscle from current motion $\boldsymbol{\Theta}'$ in previous step. e is the effect of non-target muscle calculated in (3).

If these two conditions (6) are satisfied and converged, searching calculation will be finished, and current value $(\boldsymbol{F}'_e, \boldsymbol{\Theta}')$ will be used as the solution of pinpointed muscle force control, $(\boldsymbol{F}_e, \boldsymbol{\Theta}) \Leftarrow (\boldsymbol{F}'_e, \boldsymbol{\Theta}')$. Whereas, if either condition is not satisfied, the external force $\boldsymbol{F}'_e$ and the start posture $\boldsymbol{\theta}'_0$ will be reset and go back to Step 1 to search $(\boldsymbol{F}'_e, \boldsymbol{\Theta}')$ again, until these two conditions are satisfied.

2.6 Motion and external force control (Step 5)

In the last step, if the desired force of target muscle has been realized and the effect rate has been minimized, the motion and external force will be used as the searching result, $(\boldsymbol{\Theta} \leftarrow \boldsymbol{\Theta}', \boldsymbol{F}_e \leftarrow \boldsymbol{F}'_e)$.

Human body will be controlled to realize the external force $\boldsymbol{F}_e$ and motion $\boldsymbol{\Theta}$ that found in previous steps. In this research, robot arm or dumbbell is used to control the external force. User's movement is measured by motion capture device and practice it to close the desired motion $\boldsymbol{\Theta}$.

3 Experiments

Two experiments are conducted to test this new muscle force control method for static and dynamic motion by measuring surface electromyography (EMG) signal. Before that, the accuracy of musculoskeletal model are verified first, which shows the effectiveness of muscle force estimation method. Then a robot manipulator is used to control the external force applied in human hand for static motions and dumbbells are used to control the force for dynamic motions.

3.1 Accuracy of muscle force estimation

In this experiment, 1[kg], 2[kg] and 3[kg] load are applied to the hand of subjects by holding iron dumbbells to test the musculoskeletal model for static and dynamic motion. In the experiment of static motion, the elbow joint is flexed to 90[deg]. In the experiment of dynamic motion, the elbow joint is flexed from 0[deg] to 120[deg].

The EMG signals of Biceps (BIC) were measured. The EMG measurement position is shown in Fig. 5. The data of 1[kg] was considered as the base value, which was used to calculated the change rate of muscle force in simulation and EMG signal in experiments. The accuracy of muscle force estimation is shown by estimation error, which is defined as the different of these two change rates.

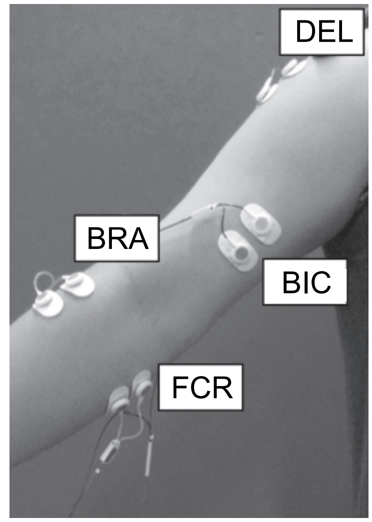


Figure 5 Measurement position of EMG electrodes. EMG signals of four muscles were measured.The muscle names and the number used in Fig.3 is:
(1) Deltoideus (DEL, No.17), (2) Biceps (BIC, No.27), (3) Brachioradials (BRA, No.28),
(4) Flexor Carpi Radialis (FCR, No.34).

Result

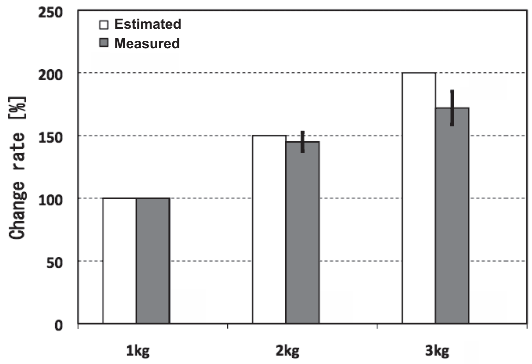
This experiment was conducted for ten male subjects. Figure 6 shows the results of change rates of estimated forces and measured values. White boxes show the change rates of muscle force estimated from musculoskeletal model; Gray boxes show the average change rates of EMG signals measured in experiments. Error lines show the standard deviation (SD) of all ten subjects.

As shown in the graphs, same changing tendencies were obtained by comparing the change of EMG signals and estimated value. The error between simulation and measurement was small enough. It shows that the musculoskeletal model is valid and can be used in rough muscle force estimation. However, EMG signal are not accurate enough to measure the amount of change since the relation between the magnitude of muscle force and the one of the corresponding EMG signals is not necessarily linear.

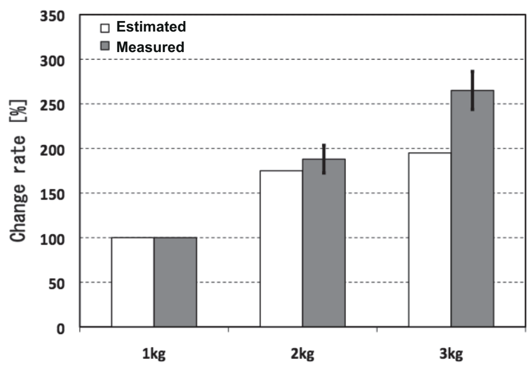
3.2 Control for static motion

The calculation of static motion experiments skipped the STEP 2 (Motion Generation) and only searched the external force $\boldsymbol{F}_e$ and the start posture $\boldsymbol{\theta}_0$.

In this static experiment, as a basic motion, the elbow joint was flexed to 90[deg] as shown in Fig.7(a). A robot manipulator (PA10, Mitsubishi Heavy Industries) shown in Fig.7(a) was used to apply the calculated external force $\boldsymbol{F}_e$ to the subjects' right hand. The tip of the manipulator can move in all three directions. A handle was designed and mounted into the tip of the manipulator in order to grasp it easily. A force sensor was set into the center of this handle to control 3 axes force in subject's hand using PID controller.



(a) Static motion: (Elbow: 90[deg])

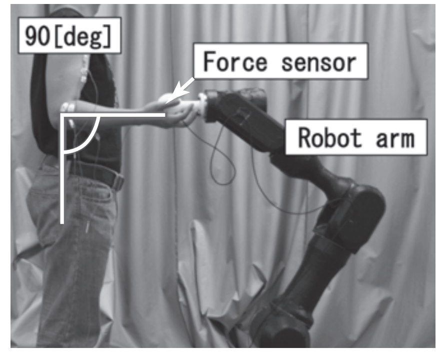


(b) Dynamic motion: (Elbow: 0-120[deg])

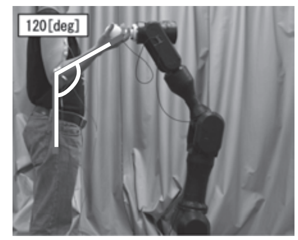
Figure 6 Result of musculoskeletal model validation. Model has been tested for static and dynamic motion when holding 1kg, 2kg and 3kg weight. The change rates rate was calculated based on the result of 1kg trail.

As an example, the angle of elbow joint and the external force have been searched to optimize the muscle force control. A 9.8[N] force was applied to the subjects' hand for calculating the nominal muscle force $\boldsymbol{f}_0$. The Biceps muscle (BIC) was the target muscle and the desired muscle force was 3.0 times ($\gamma_{27} = 3.0$) of nominal force. Three experiments have been conducted for different angle of elbow joint. In Experiment A, the elbow joint is 30[deg], which is the posture with minimum effect of non-target muscle. In Experiment B, the elbow joint is 90[deg], which is the same posture of basic motion. In Experiment C, the elbow joint is 120[deg], which is the posture with maximum effect.

EMG signals of four muscles shown in fig. 5 were measured to check the change of muscle force. The target muscle Biceps, BIC and other three non-target muscles: Deltoideus (DEL), Brachioradials (BRA) and Flexor Carpi Radialis (FCR). Figure 5 shows the measurement positions of all muscles. Note that, though it has been confirmed that the EMG signal has a close relationship with muscle force in past research (Kumar 1999), it still are not completely-consistent since the relation between the magnitude of muscle force and the one of the corresponding EMG is not necessarily linear. Therefore, in this research, the changing tendencies of estimated and measured values are compared mainly to confirm the validity.



(a) Elbow: 90[deg] (Exp. B)



(b) Elbow: 30[deg] (Exp. A) (c) Elbow: 120[deg] (Exp. C)

Figure 7 Control for static motion using a robot manipulator(PA10). Three static postures were tested (Exp. A-C) while elbow joint was 30, 90 and 120 [deg]

Result

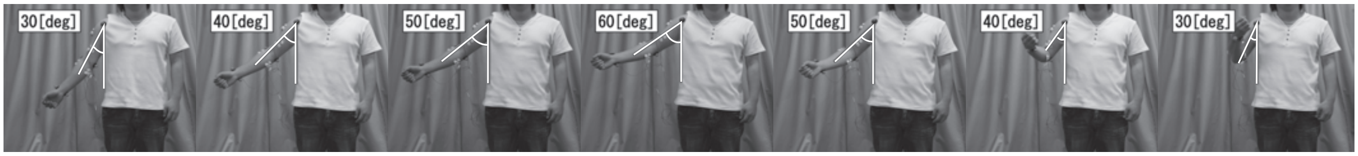
This experiment was conducted for 10 healthy male subjects. Figure 8 shows the results of all subjects. White boxes show the desired values and gray boxes show the values calculated from the measured EMG signals.

Figure 8(a) shows the change rates of target muscle. In both Experiments A, B and C, the same tendencies were gained and the target muscle (Biceps) has been controlled in both these two experiments. Figure 8(b) shows the effect rate of non-target muscle of three measured non-target muscle. Same as the result estimated in simulation, the effect of non-target muscle in Experiment A was smaller than that in Experiment B and C.

3.3 Control for dynamic motion

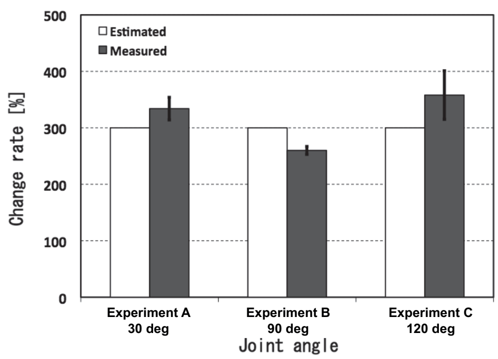
In this experiment, as a basic motion, the elbow joint flexed from 0[deg] to 120[deg] in about 4 seconds. The movement of each joint was slow enough and can be regard as a quasi-static motion. Since it is still difficult to control the external force in movement using the robot manipulator, dumbbells were used to apply downward external force $\boldsymbol{F}_e$ only. A 0.5[kg] load was applied to the hand of subjects by holding a dumbbell for calculating the nominal muscle force as shown in Fig.9. The EMG signals of same four muscles were also measured in the experiments.

As an example, the Deltoideus muscle was set as the target muscle and the desired muscle force was also set to

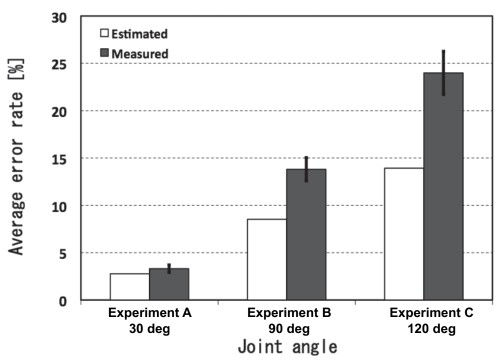


(a) Elbow: 0[deg] (b) Elbow: 20[deg] (c) Elbow: 40[deg] (d) Elbow: 60[deg] (e) Elbow: 80[deg] (f) Elbow: 100[deg] (g) Elbow: 120[deg]

Figure 10 Subject's movement of Experiment B. Elbow joint was moved from 0 to 120 as desired. Shoulder joint moved up to about 60[deg] and then moved back near to initial posture.



(a) Change rate of target muscle



(b) Effect rate of non-target muscle

Figure 8 Experiment result of static motion

3.0 times of nominal force ($\gamma_{17} = 3.0$). Two experiments have been conducted for different angle of elbow joint. In Experiment A, other joints are fixed and only searched the external force; in Experiment B, the shoulder joint was also searched using our algorithm to reduce the effect of non-target muscle.

Result

This experiment was also conducted for 10 healthy male subjects. The subjects' movement in experiment is shown in Fig. 10, which was calculated in simulation. Figure 11 shows the results. Same as shown in previous figures, white boxes show the desired values and gray boxes show the values calculated from the measured EMG signals.

Figure 11(a) shows the change rates of target muscle. In both Experiments A and B, the same tendencies was gained and the target muscle (Deltoideus) almost has been controlled to the target muscle in both these two experiments. Figure 11(b) shows the effect rate of non-target muscle of three measured non-target muscle, Biceps, Brachioradials and Flexor Carpi Radialis. As shown in the result estimated by the proposed algorithm, the effect of non-target muscle in Experiment A was larger than that in Experiment B.

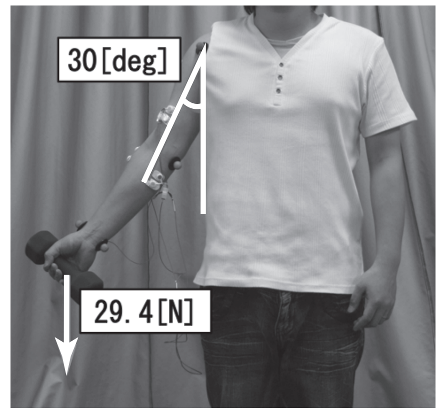
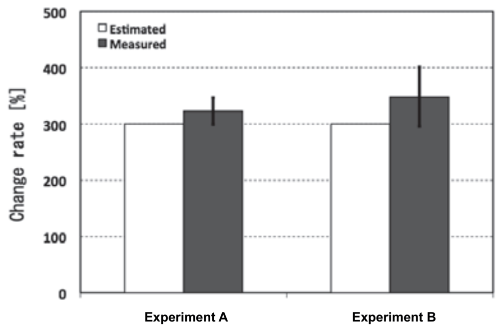


Figure 9 Control for dynamic motion using dumbbell. 3[kg] dumbbell was used. Elbow joint 0[deg] and Shoulder joint 30[deg] were used as initial posture.

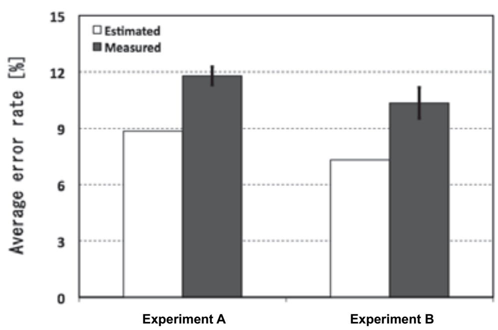
4 Discussion and Future Work

In this paper, we proposed a new pinpointed muscle force control method to reduce the effect on non-target muscle by optimizing the motion and the external force simultaneously. The combinations of human motion and external force to human body enlarge the search space too much to find out the best one. In order to reduce the computational cost, a five-step algorithm was designed to find a good enough suboptimal. After checking the accuracy of the developed musculoskeletal model, two experiments for static and dynamic motion were conducted. The measured EMG signals and the estimated value had same tendencies, which verified the effectiveness of the method proposed in this paper.

In the experiment of static motion, by controlling a robot manipulator to apply a external force to human hand, we can give a almost same load to target muscle (Biceps) for different human postures (different angles of elbow joint). However, by changing the human posture, the effective of non-target muscle also changed. We still did not get completely same change rate between between estimated and measured values because of the estimation error of our musculoskeletal model and the measurement



(a) Change rate of target muscle



(b) Effect rate of non-target muscle

Figure 11 Experiment result of dynamic motion

error of EMG. However the same change tendency can show the best range for controlling target muscles. In the future, if we can use or develop a more detail musculoskeletal model, it will be possible to get more accurate force control.

In the experiment of dynamic motion, we also obtained same tendency between estimated and measured values. Besides the errors from model and EMG measurement, some error also obtained because it is still difficult to let subjects control themselves to reproduce the calculated motion. This difficulty also limited the number of joints that were used in calculation and control. Even so, using the control algorithm, we also obtained a lighter burden motion. The motion also was verified by subjects. Only slow human motion (quasi-static motion) can be used in our control method becasue of the limitation of the musculoskeletal model. However, the movement of most general rehabilitation and trainning is not so fast and our method can be applied. In the future, we need to control the external force and the motion (posture) simultaneously to enhance high accuracy. The verification of this method need to be tested more detail in more experiments by calculating and controlling for more joints.

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