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Extension of the Upper Extremity with Shoulder Movements

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***Abstract*—In this paper, we investigated characteristics of human's upper limb extension with shoulder movements when the grasped object was moved from one point to other point. In cases where the goal position is put in a farther place than the length of the extended arm, not only the velocity profile of the hand by extension exercise but also that of the shoulder by anteflexion exercise are bell-shaped. These two exercises are simultaneously performed, but the hand velocity becomes a peak earlier in comparison with the shoulder one. Reproducing the measured human data, the exercises of a three-link arm with shoulder or body movements are simulated and the characteristics of a human-likeness fusion are examined by shifting the start time of the shoulder movement. As an evaluation result, it was found that the relation between the velocity peak positions of the hand and shoulder remarkably influences on the human-likeness.**

***Index Terms*—human arm, psychological evaluation, extension, simulation**

I. Introduction

In recent years, robot is becoming our familiar existence and robot motion must have been planned so as not to give us a threat, sense of incongruity in the action generations. Especially, in cases where robot is working around us and it has something interaction with us, movement of hand and arm may play an important role as a man-machine interface. The structure of a human upper limb is similar to the robot manipulators, and the human schemes of the arm movements are thought to be available for the control of a robot manipulator. Therefore, many investigations regarding the human arm movements have been done. In order to do the advanced work, the arm movements with a restriction to the hand were also investigated. Tsuji *et al*. [1]-[3] examined the crank rotation tasks performed by the human and examined how the arm postures were determined by utilizing kinematic redundancy. Tanaka *et al*. [4]-[6] investigated the characteristics of the hand trajectories in the manipulation of a holding non-holonomic car. If the movement range of hand is spread, the antiflexion exercise, rotation of the upper trunk, or the legs exercises are required. Sato and Sugano [7] carried out the experiment in handling a manipulator based on a guide shaft with body movements and applied the obtained human's characteristics to task planning for a mobile anthropomorphic manipulator. Such a motion composed of the plural exercises, termed the fusion motion, may include a clue for the optimal planning of the Humanoid Robot in the complex tasks. However, only few studies concerned with the fusion motions have so far been made. We investigated the human's fusion motions composed of extending the upper limb and bending the trunk of upper body and examined how these exercises were fused. Utilizing the measured data, the simulation tool which could be shifted the action start time of the two exercises was made for subjectivity evaluations to clarify the special feature of the fusion exercises without sense of incongruity.

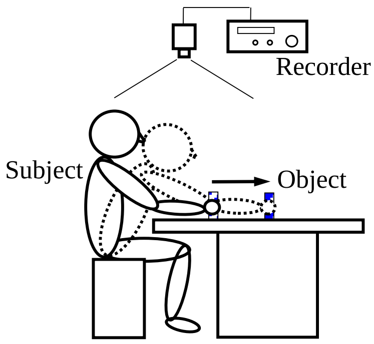

Figure 1. Experimental scene.

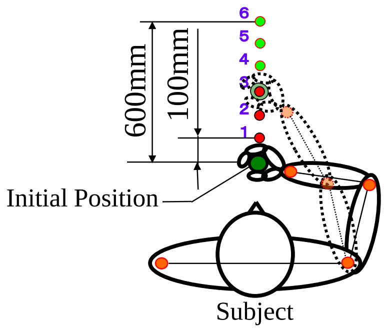

Figure 2. Distribution of target.

II. Upper Limb Extensions with Shoulder Movements

A. Experiment

First of all, we measured human's upper limb extensions with shoulder movement. In the experiment,

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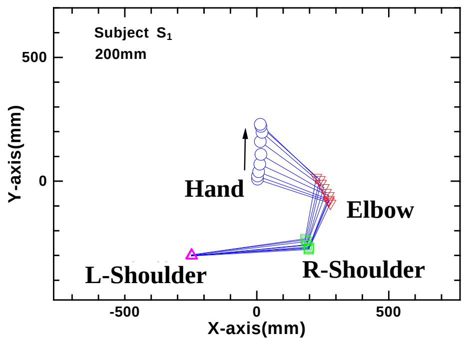
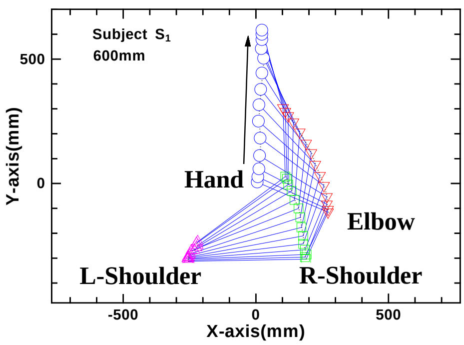
human subjects grasped a cylindrical plastic object (10[mm] 90[mm], 50[g]) and moved it toward a goal position. The participated subjects were directed so as not to stand from the chair, therefore, the grasped object was translated to the goal positions by both extension exercise of the upper limb and anteflexion exercise of the upper part of the body as shown in Fig. 1. The trajectories of the shoulder, elbow, and wrist were measured by shooting them with the digital video camera placed at the upper part 1700[mm] of the table. Fig. 2 shows the distribution of the goal positions and the posture of the subject in the initial state of the experiment. Before starting each trial, subjects extended the arm straightly with the hand located at the point 3 so as to determine the chair position (Condition I). After that, keeping the posture of the body, the upper limb was bent and the hand was returned to the initial position (Condition II). Each next position of six goals and the initial position was distributed with 100 [mm] span. The healthy human subjects aged from 21 to 24 participated in this experiment.



(a) 200mm



(b) 600mm

Figure 3. Trajectory of upper limb and shoulders.

B. Results

Experimental results are shown in Fig. 3. Fig. 3(a) and (b) show the trajectories of the upper limb and body under the conditions that the span to the goal was set to 200[mm], 600[mm]. The goal is near the initial position (Fig. 3(a)), the movement of the grasped object is carried out by only extending the upper limb without moving the shoulder. On the other hand, when the movement span is longer than the arm length (Fig. 3(b)), it can be confirmed that the shoulder also moves to the goal position with extending the upper limb. Especially, the right shoulder moves to the frontal direction remarkably compared with the left one, therefore, the anteflexion exercise is performed with the rotation of the trunk with respect to its major axis. In order to investigate the upper limb exercise without the movement of the shoulder, the right shoulder position is set to the origin of the upper limb and the hand is re-defined as follows:

$$\bar{P}_i^{Hand} = P_i^{Hand} - P_i^{R-Body} \quad (1)$$

where, $P_i^{Hand} = [x_i^{Hand} \quad y_i^{Hand}]^T \ (i = 0,1,2,\cdots,N)$ is the measurement point of the hand including the shoulder movements, and $P_i^{R-Body} = [x_i^{R-Body} \quad y_i^{R-Body}]^T$ indicates the right shoulder as shown in Fig. 4. Fig. 5 shows the time trajectories of a tangential velocity concerning with the hand position P_i^{Hand}, the right shoulder position P_i^{R-Body}, and the relative hand position $\bar{P}_i^{Hand}$ defined in (1). The hand and right shoulder are moving with the bell-shaped velocity profile. The velocity of the relative hand position is also bell-shaped and it can be confirmed that both extending exercise of upper limb and anteflexion exercise synchronize each other. However, there is some temporal difference with respect to the location of the peak value in the velocity profile. Fig. 6 shows the time when the velocity of the right shoulder position P_i^{R-Body} and relative hand position $\bar{P}_i^{Hand}$ become a maximal value, which is normalized with that of the measured hand position P_i^{Hand}. The value of $\bar{P}_i$ is approximately 1.0 across the subjects, and the velocity of the hand created by expanding the upper limb has a maximal value in the same time as that of the hand including the shoulder movement. With reference to the temporal order, the values of $\bar{P}_i^{Hand}$ reach a peak earlier in comparison with that of P_i^{R-Body} regardless of the goal position. Namely, the hand movement by the upper limb exercise has a peak earlier in comparison with the shoulder movements.

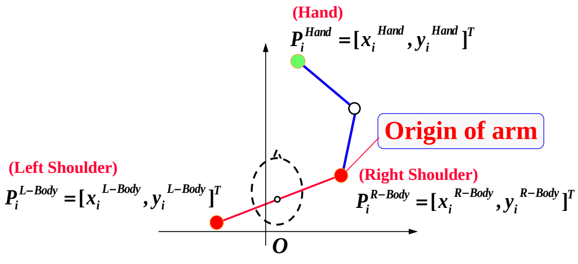


Figure 4. Frame model.

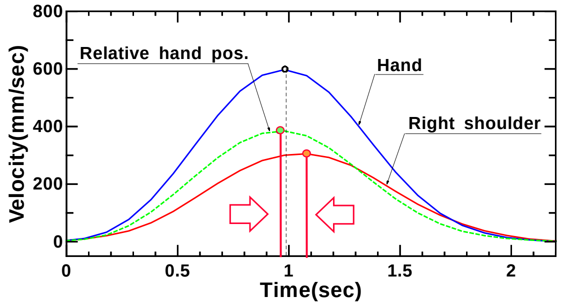


Figure 5. Velocity profile.

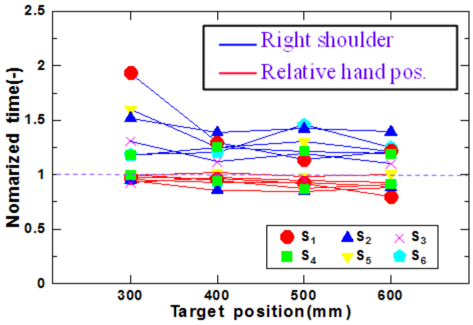


Figure 6. Peak position of time duration.

III. Psychological Evaluations

A. Simulation

From the temporal point of view, there are numerous combinations between the shoulder movement and the exercise of upper limb extension. In this section, we investigated the permission ranges of the temporal difference between the starting times of the two exercises so as to generate the fusion motions just like a human without the sense of incongruity. Here, the simulation tool which could shift the start time of the shoulder movement with respect to that of the arm movement was made in order to display a frame model on a computer CRT, and subjects watched and evaluated these motions. As shown in Fig. 7, the length of the shoulder, brachium, and forearm is $2l_1$, l_2, and l_3, respectively. In the coordinates (x, y) whose origin is the point O, the time trajectory of the hand $\hat{P}_i^{Hand} = [\hat{x}_i^{Hand} \quad \hat{y}_i^{Hand}]^T$ $(i = 0,1,2,\cdots,N)$ is given by

$$\hat{P}_i^{Hand} = \tilde{P}_i^{Hand} - P_{i+\kappa}^{Body} \tag{2}$$

where,

$$\tilde{P}_i^{Hand} = [\tilde{x}_i^{Hand} \quad \tilde{y}_i^{Hand}]^T = \begin{bmatrix} l_1\cos\theta_1 + l_2\cos(\theta_1+\theta_2) + l_3\cos(\theta_1+\theta_2+\theta_3) \\ l_1\sin\theta_1 + l_2\sin(\theta_1+\theta_2) + l_3\sin(\theta_1+\theta_2+\theta_3) \end{bmatrix}, \tag{3}$$

$$P_{i+\kappa}^{Body} = \left[\frac{x_{i+\kappa}^{L-Body} + x_{i+\kappa}^{R-Body}}{2} \quad \frac{y_{i+\kappa}^{L-Body} + y_{i+\kappa}^{R-Body}}{2}\right]^T. \tag{4}$$

$\tilde{P}_i^{Hand}$ indicates the hand position in the coordinate (x', y') where the origin is set to the point of $P_{i+\kappa}^{Body}$. The joint angle θ_1, θ_2 and θ_3 are measured data generated by the subjects as shown in Fig. 8. Regarding the human motions, the angle θ_3 is remarkably changed, and the exercise of upper limb expand is actively performed until the hand reaches the goal position. Moreover, we can see that the anteflexion of the trunk synchronizes with the extension exercise of the upper limb. $P_{i+\kappa}^{Body}$ is the body position in the static coordinates and it is derived by modifying the measured data P_i^{L-Body}, P_i^{R-Body} as shown in Fig. 4 and by moving the time as $i+\kappa$. Fig. 8 also shows the example of the time trajectories in cases where the start time of the body $P_{i+\kappa}^{Body}$ is changed($\kappa = 0, 20$). In the lower figure, the body position $P_{i+\kappa}^{Body}$ in the static coordinates (x,y) is shown. For the parameter κ of 20, we can see that the body starts moving after the exercise of the upper limb extension has been started. Fig. 9 shows the velocity profile of the hand and body positions in the static coordinates. The data of $P_{i+\kappa}^{Body}$ were prepared for the evaluations by moving the starting time of the body ($\kappa = 0, \pm 10, \cdots, \pm 50$). Ten frame moving is equal to 1/3 [sec] (one frame is 1/30[sec]) and maximal difference compared with the original measured data is $\pm 5/3$ [sec].

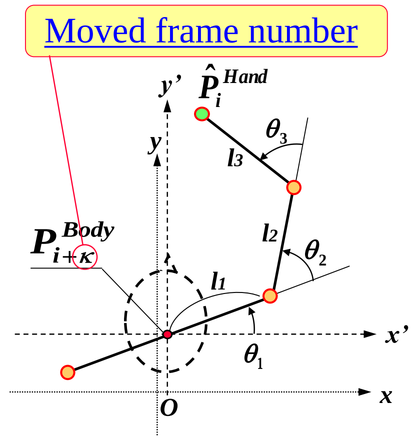


Figure 7. Frame model for simulation.

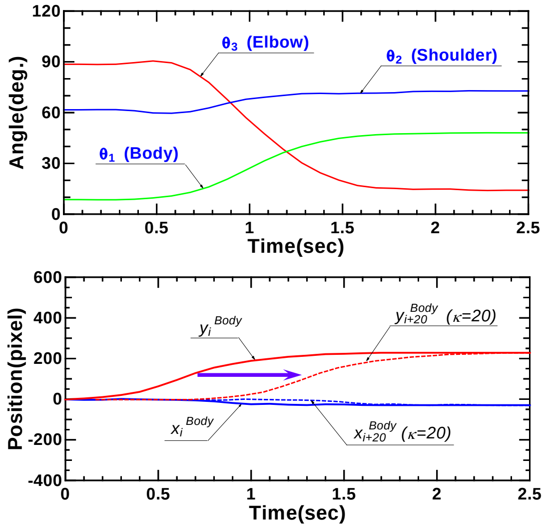


Figure 8. Example of simulation.

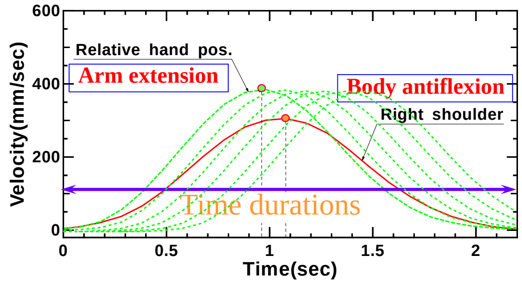


Figure 9. Velocity profile for evaluations.

B. Evaluation

Human subjects watched the simulations displayed on a computer CRT and evaluated their motions. The indicated fusion exercises were inspected with the method conformed to rating scale method used for the psychological evaluations of robot motions [8]-[10]. Here, we used five adjectives (smooth - awkward, fast - slow, careful - careless, skilled - unskilled, and human like - un-human like"). The subjects were instructed to emulate the indicated motions on a computer CRT by synchronizing it with the actual exercise of the upper limb and anteflexion so as to make it easy to feel the sense of incongruity concerning with the fusion exercise. According to the subject's requests, they could watch the simulations repeatedly. Before the experiments, the evaluation sheets were given to the subjects and they were filled with their impressions by painting the circle at any of the seven stage scales about the five adjectives. Eleven simulation patterns were prepared and indicated from $\kappa = -50$ to $\kappa = +50$ in order. Thirty healthy subjects aged from 21 to 39 participated in this experiment.

C. Results

The results of subjectivity evaluations are shown in Fig. 10. Each point is mean value of all subjects, and the vertical short bars indicate the standard deviation. In cases where the parameter κ was a negative, the body moves before the upper limb extending. For the case of a positive, the above temporal order to start moving was replaced. With reference to the evaluations for the human like motions, when the two exercises started simultaneously ($\kappa = 0$), the fusion motion was felt most human like. In the case of $\kappa = \pm 10$, the mean value was located at the left side to the center scale (neither-nor), the boundary of the adjective pairs, and the fusion motions were carried out without sense of incongruity even though whichever of the two exercises starts to move previously. On the other hand, in the case of $\kappa = \pm 20$, the standard deviation was larger compared with the other circumstances, so there were some differences concerning with the evaluations across the subjects and some of them had a feeling of un-human like. If the absolute value of κ was more than 30, all subjects felt a sense of incongruity. In Fig. 9, in order to make a human like fusion motions, the bell-shaped velocity profile of the body must have reached a peak value by the time when the arm extending motion was completed, in cases where the arms exercised an exhibition previously ($\kappa > 0$). If the body started to move previously ($\kappa < 0$), the exercise of extending the arm must have started before the movement of the body reached a velocity peak. In the evaluations regarding the smoothness, speed, and skill, there was a same tendency as that of the human like. Each adjective was felt strongly when the parameter κ was zero, and all feeling boundary were focusing on the circumstance of ± 20. According to the increase of the temporal difference between the two exercises, "awkward", "slow", and "unskilled" were strongly felt. The trend regarding the prudence feeling was differed from other, the subjects tended to feel careful motions as the temporal difference was longer.

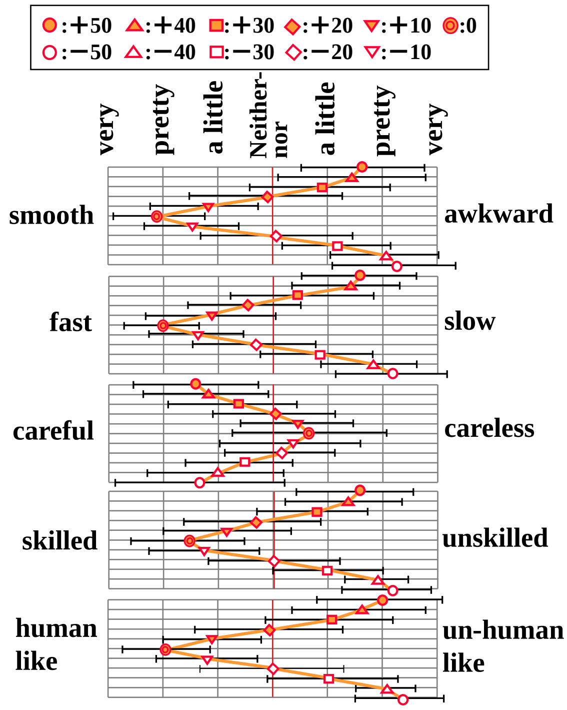


Figure 10. Evaluation results.

IV. Conclusions

In this paper, we investigated the human's upper limb extensions and shoulder movements. Experimental results said that velocity profile of both upper limb and shoulder were a bell-shaped and hand velocity became a peak earlier in comparison with the shoulder one. The motions of upper limb extension and body movement were simultaneously performed and it could be confirmed that the relative position of the velocity peak remarkably influenced on a human-likeness. The obtained results may imply a clue of the optimal motion planning for arm manipulator working around us humans. In cases where the robot needs to extend the arm with the body movements, the temporal difference between the starting times of the two exercises must be considered in order to remove a threat and sense of incongruity.

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