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Experimental Study on Human Arm Motions in Positioning

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Abstract

In this paper, characteristics of the motions of a human arm are investigated experimentally. When the conditions of the target point are restricted, human adjusts its trajectory and velocity pattern of the arm to fit the conditions skillfully. The purpose of this work is to examine the charasteristics of the trajectory, velocity pattern, and the size of the duration in the following cases.

First, we examine the case of point-to-point motion. The results are consistent with the minimum jerk theory. However, individual differences in the length of the duration can be observed in the experiment.

Second, we examine the case which requires accuracy of positioning at the target point. It is found that the velocity pattern differs from the bell shaped pattern explained by the minimum jerk theory, and has its peak in the first half of the duration. When higher accuracy of the positioning is required, learning effects can be observed. Finally, to examine the case which requires constraint of the arm posture at the target point, we conduct experiments of a human trying to grasp a cup. It is considered that this motion consists of two steps : one is the positioning motion of the person in order to start the grasping motion, the other is the grasping motion of the human's hand approaching toward the cup and grasping it. In addition, two representative velocity patterns are observed : one is the similar velocity pattern explained in the above experiment, the other is the velocity pattern which has its relative maximum in the latter half of the duration.

1 Introduction

In the future, it is expected that robots play an important role coexisting with humans in such fields as nursing in a hospital, service in a family or in a work place. When we consider robots coexisting with humans as such above cases, it is ideal that robots understand the purpose of human motions, find effective motions which can reduce human physical, mental load, and draw out human ability for the purpose. In order to realize such intelligent ability as this, it is necessary to study human motions sufficiently.

One of the important human motions that robots have to consider is the arm motion. When a human and a robot work together, such as holding of handing an object, they have to use their arms. Therefore, arm motion has to be analyzed in depth.

There exist some papers on analysis of human arm motion. Dr. Ogawa Mori[1] conducted an experiment where a human moves an object in a straight line using a cart, and obtained experimental formula about the velocity of human hand. He clarified that velocity pattern changes with the nature of the object and the positioning accuracy of the target point.

Dr. Flash Hogan[2] proposed a model that a hand trajectory on the plane is determined by minimizing the square of the derivative of the acceleration under the condition that the movement duration is given.

However, in the daily life, there seldom exists the task whose trajectory is restricted to straight line as in Dr. Ogawa Mori's experiment or whose duration is given as in Dr. Flash Hogan's experiment. In this paper human arm motions are examined considering above mentioned fact. First, point-to-point motions are examined under the condition that the duration is determined by the human. Second, point-to-point motions are examined under the condition that the positioning accuracy is required at the target point. Third, we conduct experiments that a human tries to grasp a cup to examine motions which require constraint of positioning accuracy and direction of the hand at the target point.

2 Mathematical models of human point-to-point arm motion[1][2]

The following mathematical models have been proposed about human arm point-to-point motion on the plane.

(1) First order delayed velocity model

Ogawa, Mori[1] proposed the experimental velocity formula of the human arm straight motion when human holds an object under the condition that mass of the object, trajectory (straight line), the distance of the motion, and three positioning accuracy ($\pm$ 10mm, $\pm$ 5mm, $\pm$ 0mm) are given

$$V(t) = k\left(\frac{t}{a}\right)^{b}\exp(-ct-dt^{2}) \qquad (1)$$

where t is time, $V(t)$ is the hand velocity, k, a, b, c, d are experimental parameter which will be estimated by experimental data. This formula is well consistent with the observed velocities.

(2) Minimum jerk model

Flash, Hogan[2] proposed a mathematical model which accounts for formation of hand trajectories when human moves the hand between a pair of targets. In moving from an initial to a target point in a given time t_f, the criterion function to be minimized is expressed as follows :

$$C = \frac{1}{2}\int_0^{t_f}\left(\left(\frac{d^3x}{dt^3}\right)^2 + \left(\frac{d^3y}{dt^3}\right)^2\right)dt \qquad (2)$$

The path derived from (2) is a straight line between the initial and the target point and the associated velocity profile is bell-shaped.

An example of the velocity patterns of both first order delayed velocity model and minimum jerk model is shown in Fig.1, where horizontal axis τ is normalized value of time t by the movement time t_f and vertical axis is normalized value of velocity V by the maximum velocity $Vmax$. As shown in Fig.1, first order delayed model can profile the velocity pattern whose velocity peak is not at $\tau = 0.5$ (in this example $\tau = 0.39$) in comparison with the velocity peak of minimum jerk theory always at $\tau = 0.5$.

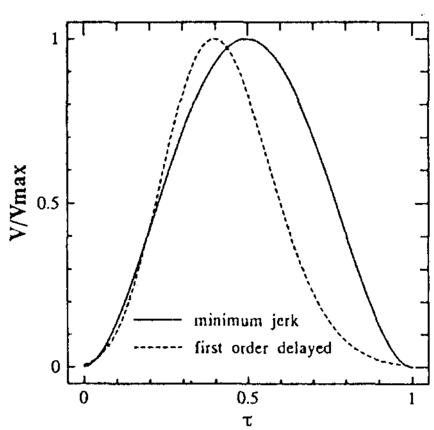


Fig.1 Representative examples of the velocity patterns of the two models

3 Point-to-point motions without constraint on the target point

Here, human upper arm point-to-point motions on the desk will be compared with minimum jerk model under the condition that the duration is not restricted.

3.1 Experimental setup and methods

Experimental setup is shown in Fig.2. Position sensor system C1373-04 (HAMAMATSU PHOTONICS K.K) is used for the measurement. Human subject sits in a chair whose height is 500mm and face to a desk whose height is 760 mm. Four LED markers are attached to the shoulder, elbow, wrist, hand of the subject respectively. And two dimensional positions of the markers are measured by a PSD camera mounted on the ceiling at the height of 1800mm. Low pass filter (cut off frequency 10 Hz) is applied to the out put data in order to remove high frequency noise.

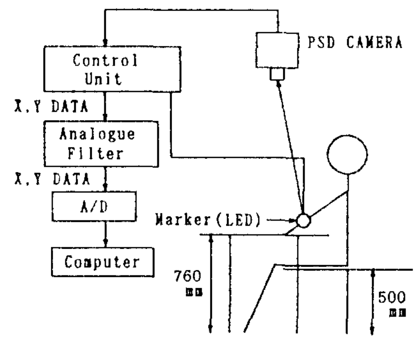


Fig.2 Measurement system

The starting point A, target point B, C, D (circle whose diameter is 50 mm) are in the desk plane as shown in Fig.3.

The subject is instructed to move his hand from the starting point A to one of the target points according to the sign of the start. This motion is conducted to all the target point B, C, D in arbitary order. This procedure is performed three times to five students.

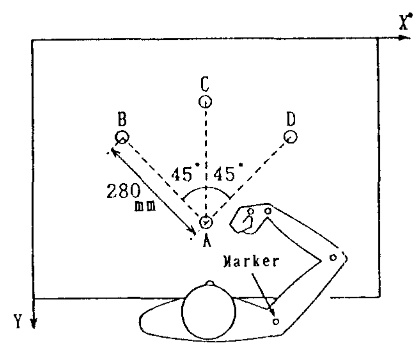


Fig.3 Geometical assignment of points and joint angles

In the experiment, the duration and the trajectory of the subject's arm are not restricted. The hand motion is considered to be finished when the hand velocity becomes less than

0.01mm/sec for the first time.

3.2 Experimental results and discussion

(1) Trajectory

Representative examples of the motions of the joint are shown in Fig.4. Fig.4(a)~(c) show the movements of the shoulder, elbow, wrist, and hand from the start to the end also shows the momentary posture (what connect between shoulder and elbow, elbow and wrist, wrist and hand respectively) of the upper arm at the constant time interval.

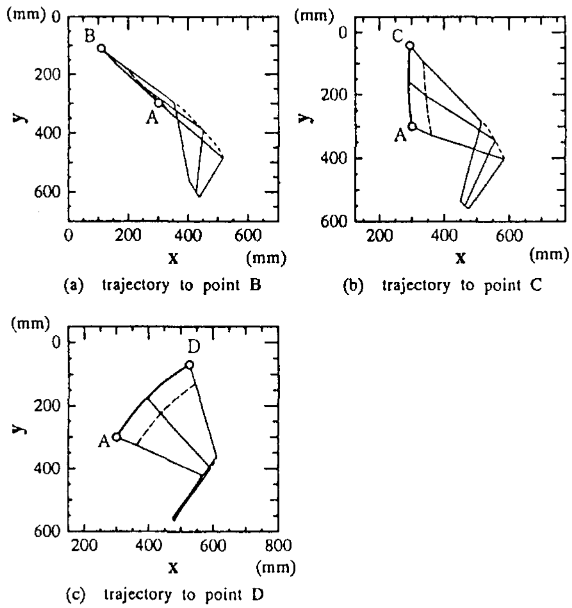


Fig.4 Trajectories of the markers of upper link for point-to-point movements

Experimental results show that the trajectory of the motions from A to B and A to C is nearly straight explained by the minimum jerk theory. However, the trajectory of the motion to target D forms a curve like an arc.

(2) Velocity and duration

The results of the hand velocity are shown in Fig.5. Here, the velocity data are at the sampled point on the trajectory, which is calculated numerically from the position data[3]. Note that horizontal axis indicates the time. As shown in the figure, the hand velocity of all the motions forms a symmetrical bell-shaped velocity pattern explained by minimum jerk theory. Also, the duration of the three motions are nearly equal.

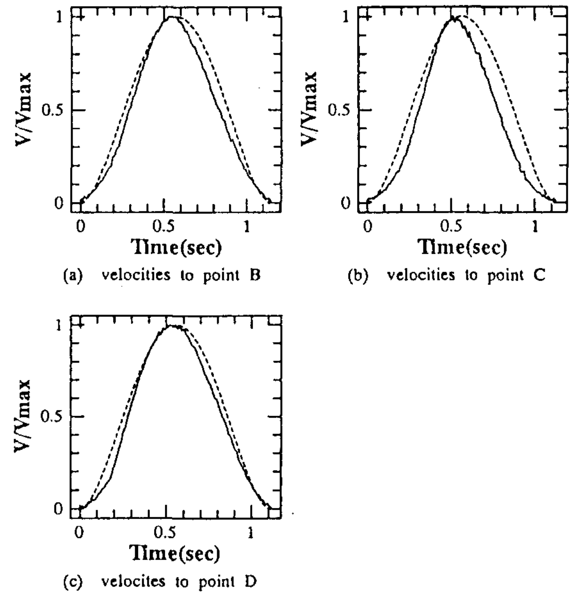


Fig.5 Hand velocities for point-to-point movements

The velocity peak position and the duration of all the subjects for the targets B, C and D are shown in Fig.6. Here, the vertical axis of Fig.6(a) indicates the velocity peak position normalized by the duration, and the results in the figure are average values of the three trials. As shown in Fig.6(a), the velocity peak position of all the subjects is nearly 0.5 for all target points. In terms of the duration, individual differences were observed (Fig.6(b)). However, the durations of each subject are almost equal for three target point.

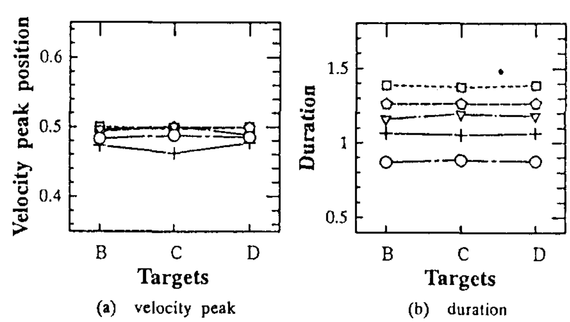


Fig.6 Changes of the velocity peak position and the duration for the individual target point

4 Upper arm positioning motions using a stick

When accuracy in positioning is required at the final position, human satisfies the accuracy by controling the hand velocity skillfully. In this section, upper arm positioning motions for two different size of the target points are conducted.

Velocity profile of each motions are also examined. The duration and the trajectory are not restricted as the former experiment.

4.1 Experimental setup and methods

We conduct the experiment, in which a human grasps a wooden stick whose mass is 3g with the full palmar prehension[4] and moves the tip of the stick from the starting point to the target point according to the sign of the start. The stick is light enough to ignore the load acting on human arm, therefore the subject can concentrate on the positioning motion (Fig.7). Here, the target points are circles whose diameter is 10mm and 2mm. The location of circles are almost the same as the target point C from the previous experiment.

In this experiment, in order to avoid the transfer of performance [5], the group of five students repeat either motion ten times.

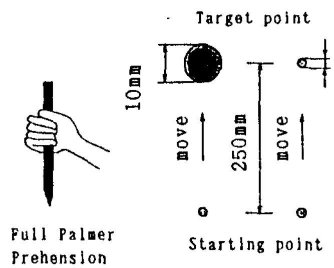


Fig.7 Grip style and target points

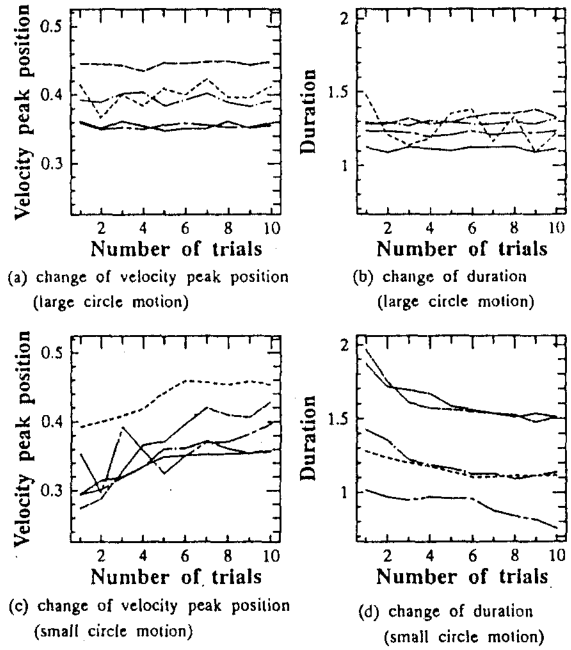
4.2 Experimental results and discussion

In the motion to the large circle (we call this motion "large circle motion" from here) and to the small circle (we call this motion "small circle motion" from here), all subject's hand trajectory are near to a straight line as in the minimum jerk theory.

Here, Fig.8(a) shows the relation between the number of trials and velocity peak position and Fig.8(b) shows the relation between the number of trials and duration of all the subjects' when attempting large circle motion. Also, Fig.8(c) and Fig.8(d) are about small circle motion.

(1) The characterictics of velocity pattern

The results show that the velocity profile has its peak in the first half of duration. Therefore this motion can not be explained by minimum jerk theory.



(a) change of velocity peak position (large circle motion)
(b) change of duration (large circle motion)
(c) change of velocity peak position (small circle motion)
(d) change of duration (small circle motion)

Fig.8 Learning effect

(2) Learning effect

The characteristics appear in the relation between the number of trials and the velocity peak position, and the number of trials and the duration for each motion. They are considered as follows :

1. In the large circle motion, the velocity peak position and duration are nearly constant in each subject regardless of number of attempts. Individual differences are observed about these values.

2. In the small circle motions, velocity peak position moves from the beginning of the duration toward the position in the large circle motions and the duration decreased toward the value in the large circle motions with the number of trials untill the fifth - seventh attempt. They can be regarded as learning effects. After the learning effects are observed, these value become constant. The constant value depends on individuals.

5 The motion of a human trying to grasp a cup

When the hand posture is restricted in addition to positioning accuracy at the target point, human can choose the trajectory and the velocity to satisfy these conditions. In this section, we conduct experiments that a human tries to grasp a cup on the target point, and examine the characteristics of the upper arm trajectory and the velocity.

5.1 Experimental setup and methods

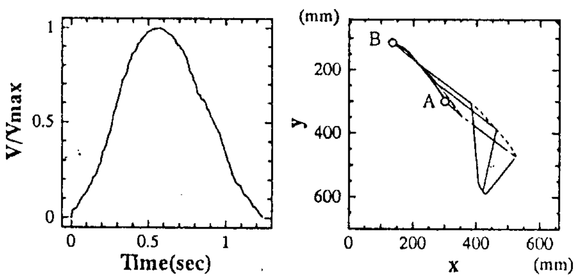
Experimental setup is the same as the former experiments and empty glasses are set on the target points B, C, and D respectively. The motion consists of trying to grasp glasses at the target points from the starting point A trying to grasp a glass from the start point A to one of target points are conducted here.

We conduct the experiment, in which a human puts his hand on the start point A with a light grasp first. The subject trys to grasp one of the glasses on the tareget points B, C, and D according to the sign of the start. This motion is conducted to all the glasses on the target point B, C and D respectively in arbitary order. This procedure is performed with five students. Since learning effects involved in the increase of the attempts are not observed, the procedure is repeated three times on each motion.

Again, the duration and the trajectory are not restricted for each subject.

5.2 Experimental results and consideration

The hand velocities, the movements of the joint and the changes of the joint angles of the subjects for each target points are shown in Fig.9~Fig.11. The results, when the



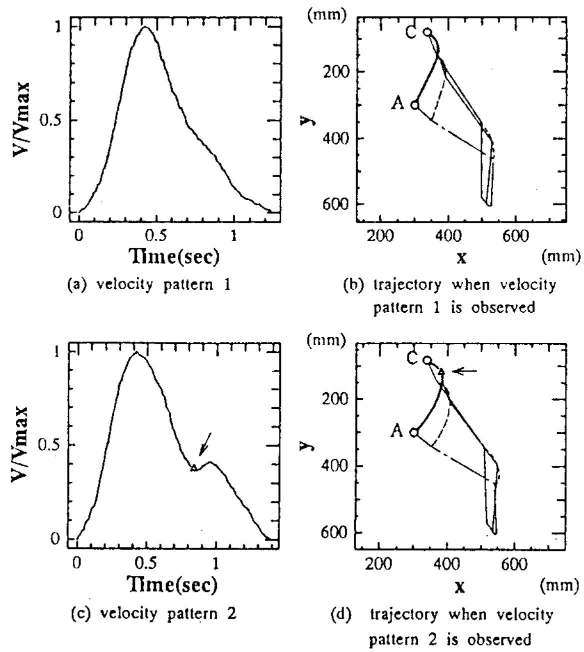
(a) velocity pattern (b) trajectory

Fig.9 Reaching a cup movements to point B

different velocity patterns of a subject are observed as (a) and (c), are shown in Fig.10 and Fig.11. Here, we call the velocity pattern in (a) velocity pattern 1 and the velocity pattern in (c) velocity pattern 2, and define them as follows :

- **Pattern 1**
  The smooth change of the velocity is observed from the start to the finish as in the first order delayed model.

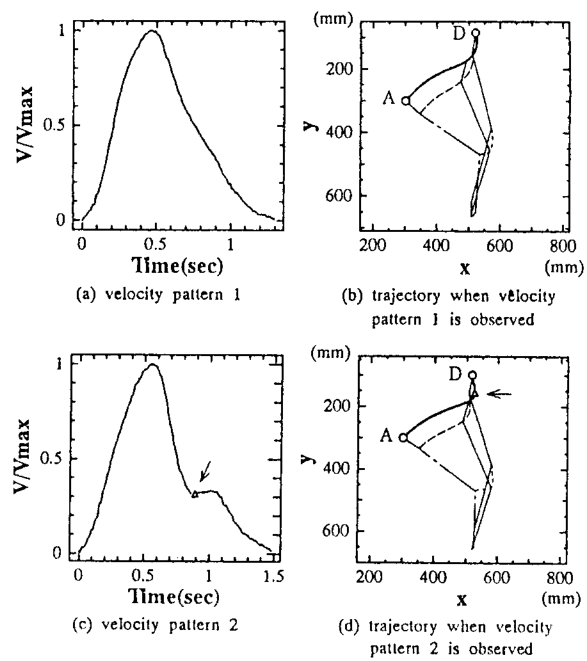
- **Pattern 2**
  After velocity peak, steep velocity slope is seen first, and the velocity slope becomes gentle for a while, and the velocity slope becomes steep again, finally the smooth decrease of the velocity is observed untill the finish.



(a) velocity pattern 1 (b) trajectory when velocity pattern 1 is observed

(c) velocity pattern 2 (d) trajectory when velocity pattern 2 is observed

Fig.10 Reaching a cup movements to point C



(a) velocity pattern 1 (b) trajectory when velocity pattern 1 is observed

(c) velocity pattern 2 (d) trajectory when velocity pattern 2 is observed

Fig.11 Reaching a cup movements to point D

Pattern 1 was observed for all the subjects in the motion to target point B. In the motions to the target point C and D, the frequency of appearance of pattern 2 depends on individual, and its characteristic change becomes large as the frequency increases.

The time at which the characteristic change begins is indicated by the triangle mark pointed by a arrow in Fig.10(d),(e) and Fig.11(d),(e).

Judging from the results, this motion consists of the approaching motion and grasping motion. The positioning motion begins with the subject shifing his hand diagonally right to the cup until the triangle mark refered in Fig.10 and 11. The motion after the triangle mark involves rotation of the wrist, but near to straight line is observed. This near to a straight line motion can be considered as the grasping motion because the human moves his hand to the object and grasping it.

When the start point of the grasping motion is far from the cup, more time is consumed at the point of transfer from the approach motion to the grasping motion(Fig.10(b), (d)), this is why pattern2 generates. On the other hand, when the start point of the grasping motion is near the cup, the subject seems to conduct the positioning motion and grasping motion successively without consuming time. Thus, pattern 1 and 2 are determined by the degree of the overlap of the positioning motion and the grasping motion.

In the motion to the target point B (Fig.9), nearly straight line are observed because the direction of the grasping motion is close to the direction from the start point to the target point. It is considered that the degree of the overlap of the motions is large, and the velocity profile becomes a smooth configuration.

6 Conclusion

It is necessary to clarify the characteristics of human motions in order to accomplish cooperations between humans and robots. From this point of view, we pay attention to human arm motions under several conditions at the target point, and examine these characteristics by conducting experiments. The obtained results can be summarized as follows :

1. In the simple point-to-point motions, both the hand trajectory and velocity are well explained by minimum jerk theory. However, the motions to right front of human, the rotational motions whose center is in his elbow are conducted. The duration is determined not by the direction but by the distance of the movement, and the size of it depends on individuals.
2. When the positioning accuracy at the target point is desired, the peak position of the velocity profile shifts to the front part of the duration but the trajectory is nearly straight line explained by minimum jerk theory. In the motions that serious positioning accuracy is desired such as small circle motion, the characteristics change with number of trials, that is, learning effects appear. The learning effects can be verified as the movement of the velocity peak position from the front part of the duration toward the center, and as decrease of the duration.
3. We conduct the motions trying to grasp a cup as an example of the point-to-point motions in which the hand posture at the target point is restricted in addition to positioning accuracy there. It is considered that this motion consists of following two motions : one is the positioning motion to the point where human can start grasping motion, and the other is the grasping motion in which human moves his wrist toward the object and grasps it. The peak position of the velocity profile of human hand shifts to the front part of the motion, and when the start point of the grasping motion is compatatively far from the object, the part of smooth decrease of the velocity in the last part of the motion is observed frequently.

These results give several important guides. For example, when a robot hands an object over to human, the hand trajectory and veloctity profile of the human are presumed based on these results and the robot can hold out his hand to the best position for the human. That is, if the robot hold out his hand from the left front of the human to the just before him, human can receive an object smoothly in short duration without rotational trajectory to grasp it.

Moreover, by further examination of the characteristics of human motions such as what mentioned in this paper, it is expected that human excellent ability can be realized in robot motions.

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