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Motion Control for Abstraction and Reproduction of Human Action

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1 Introduction

A skill transfer problem is a serious problem because expert's skills are difficult to be transferred from the experts to trainees due to aging population. Under the situation, a skill transfer technology, which provides the expert's skill to a robot, is expected to solve the problem. If the robot has the expert's skill, the robot can execute the operation instead of her/him. Moreover, the trainees can also learn the skill through the robot. For the skill transfer technology, abstraction and reproduction of the human action are significant.

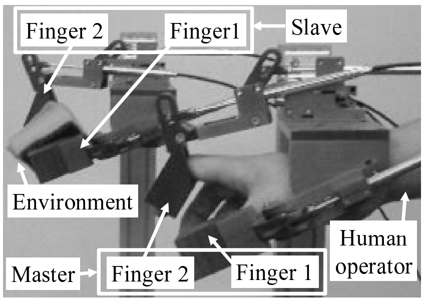
In this research, abstraction methods of the human action by using haptic information is considered at first. With these methods, the human action components can be abstracted without the constraint of the alignment of the robots [1]. Secondly, three reproduction types are proposed; timelike reproduction system, spacelike reproduction system and time-space integrated reproduction system [2]. The validities of the proposed methods are shown through experiments. In this summary, the time-space integrated reproduction system is described.

2 Structure of robot

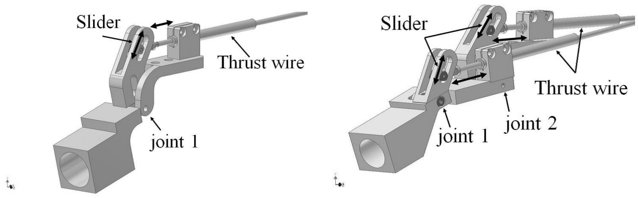
In this research, the master robot and the slave robot as shown in Fig. 1 (a) are utilized. Each robot is composed of finger shaped robots (finger 1 and finger 2). Finger 1 has one joint as shown in Fig. 1 (b) and finger 2 has two joints as shown in Fig. 1 (c).

3 Proposed reproduction system

In this section, the proposed reproduction system by using recorded data is described. The proposed system is composed of the timelike reproduction system and the spacelike reproduction system.



(a) Master-slave system



(b) Finger 1 (c) Finger 2

Figure 1: Structure of robot

3.1 Timelike reproduction system

The timelike reproduction system is designed in order to apply the expert's action force to the trainee in chronological order (*Timelike condition*). For the purpose, the goal of this system is to satisfy the condition as follows

$$f^{res}_{R,i,j}[d] \quad = \quad f^{cmd}_{R,i,j}[d]. \qquad (1)$$

To achieve the goal as shown in (1), acceleration reference vector of the finger i for the timelike reproduction $\ddot{\boldsymbol{x}}^{ref}_{R,i,time}$ is derived as follows by using a force controller C_f as follows

$$\begin{aligned}\ddot{\boldsymbol{x}}^{ref}_{R,i,time} &= \left[\ddot{x}^{ref}_{R,i,1,time}, \dots \ddot{x}^{ref}_{R,i,j,time}, \dots \ddot{x}^{ref}_{R,i,P_i,time}\right]^T \\ &= C_f \boldsymbol{M}^{-1}_{n,R,i}\left(\boldsymbol{f}^{cmd}_{R,i} - \boldsymbol{f}^{res}_{R,i}\right) \qquad (2) \\ \boldsymbol{M}_{n,R,i} &= diag\left[M_{n,R,i,1}, \dots\ M_{n,R,i,j}, \dots\ M_{n,R,i,P_i}\right]\end{aligned}$$

where $\boldsymbol{M}_{n,R,i}$ denotes a nominal mass matrix. The structure of the timelike reproduction system is shown in Fig. 2.

3.2 Spacelike reproduction system

The spacelike reproduction system is designed for the trainee to learn the way to operate the robot spatially (*Spacelike condition*). To satisfy the condition, the relations among both the joints and the fingers are considered. The structure of the spacelike reproduction system is shown in Fig. 3. In this figure, $\boldsymbol{T}_i$ and $\boldsymbol{F}_i$ denote a transformation matrix on the finger i and a filtering matrix, respectively. The filtering matrix $\boldsymbol{F}_i$ emphasizes the distinguished directionality of the feature space on the finger i. By using the transformation matrix $\boldsymbol{T}$, a velocity response vector in the feature space on the finger i $\dot{\boldsymbol{x}}'^{res}_{R,i}$ is transformed into a velocity response vector in the feature space on the robot $\dot{\boldsymbol{x}}^{res}_{R}$

The force control is implemented to the robot by using a virtual damping matrix $\boldsymbol{D}$ as follows

$$\boldsymbol{D} \quad = \quad diag\left[d_1, \dots d_i, \dots d_N\right] \qquad (3)$$

$$d_i \quad = \quad \frac{d_g}{r_i} \qquad (4)$$

$$r_i \quad = \quad \frac{\lambda_i}{\lambda_{max}} \qquad (5)$$

where d_g, r_i and λ_{max} denote standard damping, dominant ratio of the feature space and maximum value of the eigenvalues λ_i, respectively. The dominant ratio of the space r_i

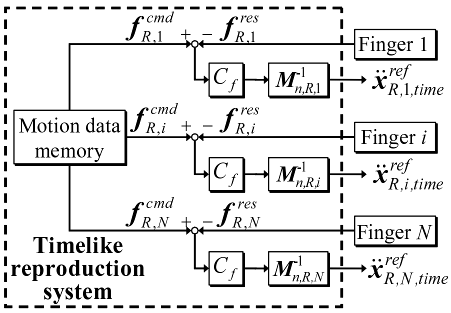


Figure 2: Timelike reproduction system

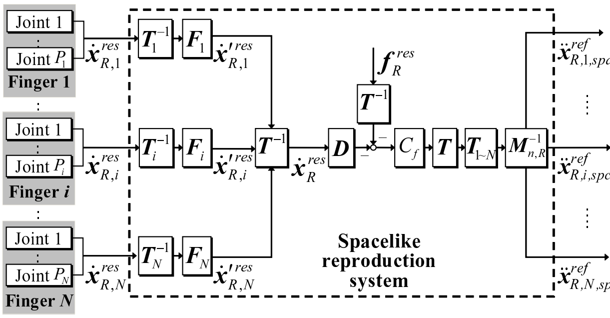


Figure 3: Spacelike reproduction system

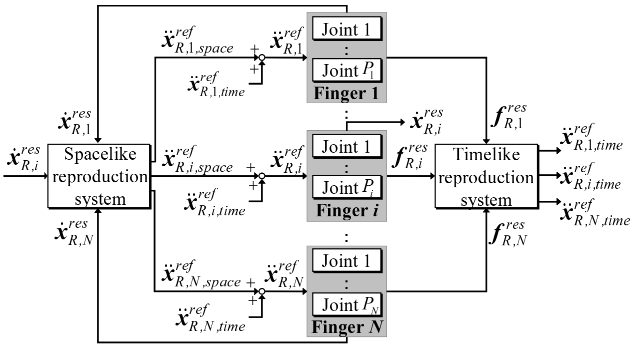
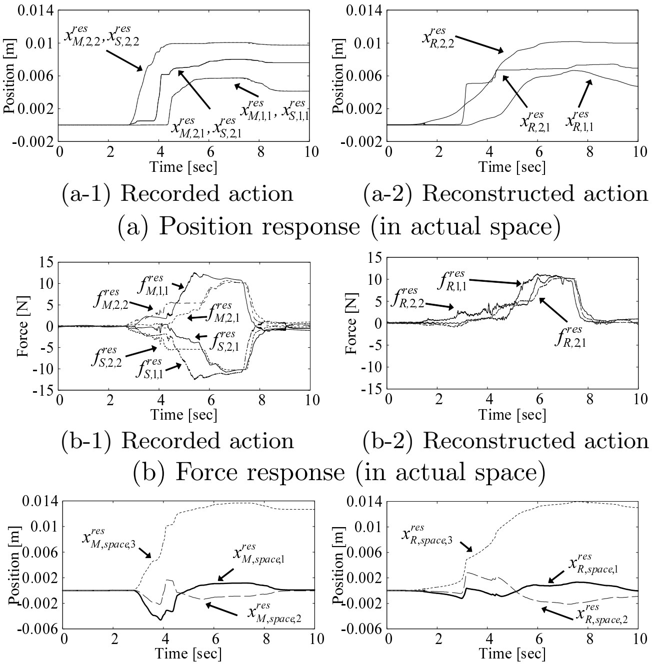


Figure 4: Integrated reproduction system



(a-1) Recorded action (a-2) Reconstructed action

(a) Position response (in actual space)

(b-1) Recorded action (b-2) Reconstructed action

(b) Force response (in actual space)

(c-1) Recorded action (c-2) Reconstructed action

(c) Position response (in feature space)

Figure 5: Experimental results.

changes the value from 0 to 1. When the dominant ratio of the feature space r_i is close to 0, the motion which corresponds to the eigenvalue λ_i is not a significant motion. Then, the trainee is not guided to follow the motion due to the virtual damping d_i. On the other hand, when the dominant ratio of the space r_i is close to 1, the motion which corresponds to the eigenvalue λ_i is a significant motion. Then, the motion is guided to reconstruct the motion due to the virtual damping d_i. As a result, the virtual damping matrix $\boldsymbol{D}$ leads the trainee to operate the robot as the expert did. Therefore, the acceleration reference to the robot is derived by using the force controller C_f as follows

$$\begin{aligned}\ddot{\boldsymbol{x}}^{ref}_{R,space} &= \left[\ddot{\boldsymbol{x}}^{ref}_{R,1,space}\cdots\ddot{\boldsymbol{x}}^{ref}_{R,i,space}\cdots\ddot{\boldsymbol{x}}^{ref}_{R,N,space}\right] \\ &= \boldsymbol{M}^{-1}_{n,R}\boldsymbol{T}_{1\sim N}\boldsymbol{T}C_f(-\boldsymbol{D}\dot{\boldsymbol{x}}^{res}_R - \boldsymbol{T}^{-1}\boldsymbol{f}^{res}_R) \quad (6) \\ \boldsymbol{M}_{n,R} &= diag\left[\boldsymbol{M}_{n,R,1},\ldots\boldsymbol{M}_{n,R,i},\ldots\boldsymbol{M}_{n,R,N}\right] \\ \boldsymbol{T}_{1\sim N} &= diag\left[\boldsymbol{T}_1,\ldots\boldsymbol{T}_i,\ldots\boldsymbol{T}_N\right].\end{aligned}$$

3.3 Time-space integrated reproduction system

The timelike reproduction system stated in the section 3.1 and the spacelike reproduction system stated in the section 3.2 are integrated in acceleration dimension. Here, the acceleration reference to the finger i $\ddot{\boldsymbol{x}}^{ref}_{R,i}$ is derived by using $\ddot{\boldsymbol{x}}^{ref}_{R,i,time}$ in (2) and $\ddot{\boldsymbol{x}}^{ref}_{R,i,space}$ in (6) as follows

$$\ddot{\boldsymbol{x}}^{ref}_{R,i} = \ddot{\boldsymbol{x}}^{ref}_{R,i,time} + \ddot{\boldsymbol{x}}^{ref}_{R,i,space}. \quad (7)$$

The proposed reproduction system based on temporally and spatially integrated reproduction of the human motion is shown in Fig. 4.

3.4 Experiment

Fig. 5 shows the experimental results of the recorded action and the reconstructed action. $x^{res}_{M,i,j}$, $x^{res}_{S,i,j}$, $f^{res}_{M,i,j}$, $f^{res}_{S,i,j}(i=1,2,j=1,2)$ and $x^{res}_{M,space,k}(k=1,2,\ldots,K, K=\sum_{i=1}^{N}P_i)$ denote the master position response, the slave position response, the master force response, the slave force response and the position response in the feature space on the master robot, respectively.

By comparing Fig. 5 (a-1) with (a-2), especially in the period from 0 seconds to 4 seconds, the trainee was guided to follow the trajectory. This result was confirmed by the result shown in Fig. 5 (c). In Fig. 5 (c-1), the variations of the first and the second position response in the feature space $x^{res}_{M,space,1}$ and $x^{res}_{M,space,2}$ were small. On the other hand, the third position response in the feature space $x^{res}_{M,space,3}$ varied significantly. Thus, the third position response in the feature space $x^{res}_{M,space,3}$ showed the feature of this motion. In Fig. 5 (c-2), the third position response in the feature space $x^{res}_{R,space,3}$ was introduced much more than the other position responses as Fig. 5 (c-1). By comparing Fig. 5 (b-1) with (b-2), especially in the period from 5 seconds to 8 seconds, the recorded force was applied to the trainee. These results showed the trainee learned the expert's motion in the view of *Timelike condition* and *Spacelike condition*.

4 Conclusions

The time-space integrated reproduction system of the human action was presented. In the timelike system, the recorded action force could be reconstructed in the same speed of the recording. In the spacelike system, the robot was operated to reconstruct the characteristic action. With the integrated method, both of *Timelike condition* and *Spacelike condition* could be achieved. The validity of the proposed method was shown through the experimental results.

References

[1] H. Kuwahara, T. Shimono and K. Ohnishi, "Abstraction of Action Components Based on Haptic Information," *Proc. of IEEE HSI 2009* pp. 196–201.

[2] H. Kuwahara, H. Tanaka, Y. Suzuki and K. Ohnishi, "A Reproduction Method of Human Motion Based on Integrated Information for Haptic Skill Education," *Proc. of IEEE AMC2010* (accepted for publication).