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Robot Skill Components for RT-Middleware

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***Abstract*— This paper describes a requirement of task skill in a service field, and a few task skill studies using our task skill transfer method. In a previous research, we have proposed a task skill transfer method using a bilateral teleoperation. In this method, it is assumed that a robot arm is implemented by the hybrid impedance/force control, and is able to execute a task by a suitable trajectory of impedance center and a suitable target force. Thus, we find the suitable trajectory of impedance center and the suitable target force using our task skill transfer method. To re-use the task skill easily, moreover, this paper comments on the need for task skill components for RT-Middleware.**

***Index Terms*— Task Skill, RT-Middleware, Component**

I. Introduction

A concept of task skill has been proposed for a dexterous manipulation. The efficiency of the task skill has been confirmed by many researches [1]–[6]. However, a target of these researches does not cover a practical task area such as a maintenance task with complicated contacts. And in these researches, it is not clear how to transfer the human's knack of the practical task with complicated tangency to the robot. Here, the skill that is able to execute the practical task with complicated tangency is called a task skill in this paper. Then the task skill performs the knack of the above tasks.

In our previous paper, we have proposed a task skill transfer method using a bilateral teleoperation system[7]. In our method, the knack of the practical task with complicated tangency can be programmed easily. Asada[8] employed the hybrid position/force control for the task skill motion. The position control is not able to absorb a positional error. Then our method employed the hybrid impedance/force control[9]. Moreover, the task skill for a simple task can be generated from the teaching data only. The task skill for a complex task needs to be generated from both the teaching data and the teaching intention (motion strategy). Both the conscious and the unconscious motions of the operator are included in the teaching data. However, the all teaching intentions are not included in the teaching data. On the contrary, the teaching intention ignores the unconscious motion of the teaching data. Then, in our task skill method, the task skill is generated from the teaching data and the teaching intention (motion strategy). In our previous papers, many task skills such as a nut attachment task skill are generated by our method[10]–[13].

In this paper, we show our task skill transfer method and a few task skill. Moreover, we comments on the need for task skill component for RT-Middleware.

II. Task Skill Transfer Method

In a previous work, we have proposed a new task skill transfer method[7]. A concept of our method is shown in Fig. 1. It is assumed that if both the condition and the behavior between the slave arm and the environment in the teleoperation can be reproduced by the task skill, the task skill can execute the task. The task skill should include the teaching data and the motion strategy. It is very important for our teleoperation system to be realized a good stability and a good response. These requests can be realized by the parallel bilateral teleoperation system[15]. Here, the operator does not use the visual information, and to use only the motion and the force information provided by the master arm.

The task skill model is composed of an initial condition, a task skill motion and a final condition. The initial and final conditions are described by the sensor value and the tip position. The task skill motion is implemented by the hybrid impedance/force control.

It is assumed that the impedance parameters of the operator are definite values since it cannot measure the changes of impedance parameters in detail during the teleoperation experiment. Therefore, the impedance center can be calculated from the position of the slave arm, the force of the slave arm and the impedance parameters. In a traditional hybrid control, the target position and the target force are used. However, the velocity of the target position and the transition velocity of the target force are also important. Then, in our hybrid control, the target compliance center position and the velocity of the target compliance center the target force and the transition velocity of the target force are used.

The process of our task skill transfer method is described as follows.

1) The operator executes a task in the parallel bilateral teleoperation system. The operator repeats the teleoperation many times until the operator finds a teleoperation procedure that can surely be executed. The motion process of the task skill is defined from the teleoperation procedure.
2) The trajectory of impedance center is calculated from the position and the force of the slave arm in the teleoperation experiment and impedance parameter.
3) The necessary information of the initial condition, the task skill motion (hybrid impedance/force control)

TABLE I

COMPLIANCE GAINS OF HYBRID CONTROL.

	x axis	y axis	z axis	roll axis	pitch axis	yaw axis
$\boldsymbol{M_i}$(inertia gain) kg	0.5	0.5	0.5	0.5	0.5	0.5
$\boldsymbol{D_i}$ (dumping gain) Nsec/m, Nm/(rad/sec)	200.0	200.0	200.0	10.0	10.0	10.0
$\boldsymbol{K_i}$ (stiffness gain) N/m, Nm/rad	500.0	500.0	500.0	5.0	5.0	5.0

TABLE II

FORCE GAINS OF HYBRID CONTROL.

	x axis	y axis	z axis	roll axis	pitch axis	yaw axis
$\boldsymbol{K_f}$ [m/N] [rad/Nm]	0.0005	0.0005	0.0005	0.05	0.05	0.05

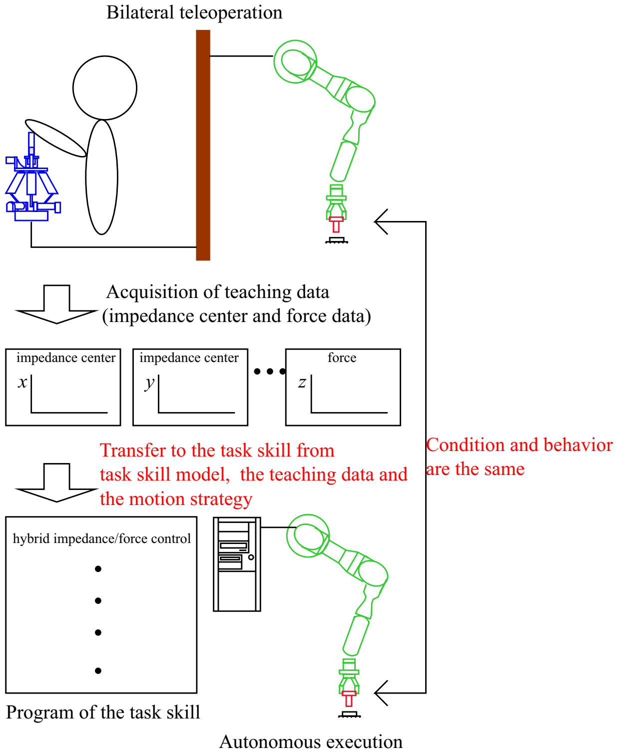


Fig. 1. Concept of the skill transfer method.

and the final condition are obtained from the teleoperation result and the impedance center. In the hybrid impedance/force control, the target compliance center and the velocity of the target compliance center and the target force and the transition velocity of the target force are needed.

III. SYSTEM ARCHITECTURE

A. Parallel Bilateral Teleoperation System

The master and slave arms are controlled by the position in low level. The scale between the master and slave arms is set to 1.

A 6-DOF compact haptic interface[16],[17] which has been developed in our laboratory is used as a master arm while a 7-DOF manipulator (PA-10), a 6 axis force/torque sensor and a parallel 2-finger hand are used as a slave arm. These arms have a good stability and a good response.

B. Task Skill Execution Robot System

The robot system is the same as the slave system of the teleoperation system. The low level control of this system is a position control and the high level control is the hybrid impedance/force control.

Table I shows the inertia gains ($\boldsymbol{M_i}$), the dumping gains ($\boldsymbol{D_i}$) and the stiffness gains ($\boldsymbol{K_i}$) for the compliance control, respectively. Table II also shows the force gains ($\boldsymbol{K_f}$) for the force control.

IV. TASK SKILLS

In this section, we show few task skills that are generated from our task skill transfer method.

A. Bolt Attachment Task Skill

An overview of the bolt attachment task is shown in Fig. 2. A bolt (M20) is gripped by the hand and a nut is locked in the environment. Σ_b is the tip coordinate system of the manipulator with its origin in O and Σ_n is the base coordinate system with its origin set N at the top of the nut.

In this task skill, Point O is set to a controlled point and is moved by the hybrid control in the task skill coordinate system (Σ_s) which is set by Σ_b. Σ_s is fixed in one point of the space and can be always reset by Σ_b. Thus, Σ_b moves with the hand, Σ_s does not move with the hand.

Here, as an initial condition, the permissible translation errors (for the x and y axes) of Σ_n are set equal to the radius of the nut and the permissible orientation errors (for the roll and pitch axes) of Σ_b are set to 0.3 rad. The distance between Point O and Point N is set less than 0.1 m.

In this task, the operator performs the task using the parallel bilateral teleoperation system. The operator manipulates Point O using the master arm.

Figure 3 shows a flowchart of the bolt attachment task skill procedure.

During the construction of this task skill, the operator used an M20 nut only. In order to demonstrate the robustness of the task skill with respect to the size of the bolt, M8, M10, M12, M16, M20, M24 and M30 bolts are used in this experiment. Moreover, in order to demonstrate the effectiveness for a variety of initial conditions, we prepared two types of experimental environments. In (I) condition, the translation error is a few millimeters and the rotation error of Σ_b is zero. In (II) condition, the translation error is a few millimeters and the rotation error of Σ_b is 0.07 rad. Altogether, this experiment is thus carried out 14 times.

All of them were successful. This task skill can execute the task at almost the same success rate as the person. And a time required of the task skill is also the same as that of the person. As an example, the nut attachment task that used M20 nut in (II) is shown in Fig. 5. In this experiment,

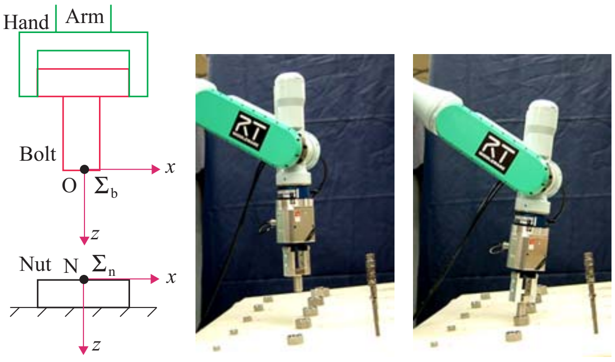


Fig. 2. Bolt attachment task.

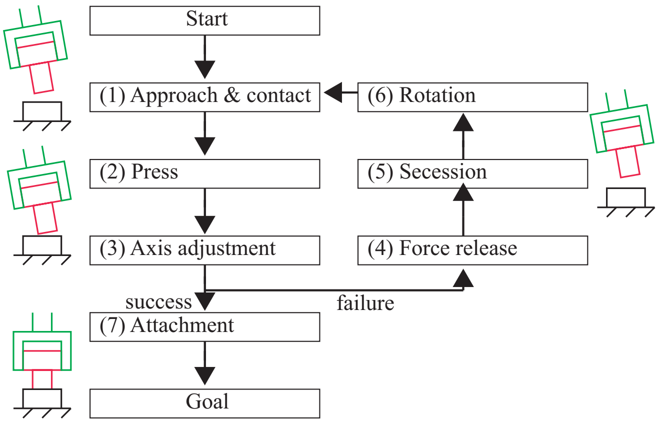


Fig. 3. Flowchart of bolt attachment task skill procedure.

the axis adjustment was not failed. Then, the procedure of this experiment is (1), (2), (3) and (7). A translation error and a rotation error can be observed in these figures. The evaluation criterion also can be observed 4 times from 65 to 80 sec.

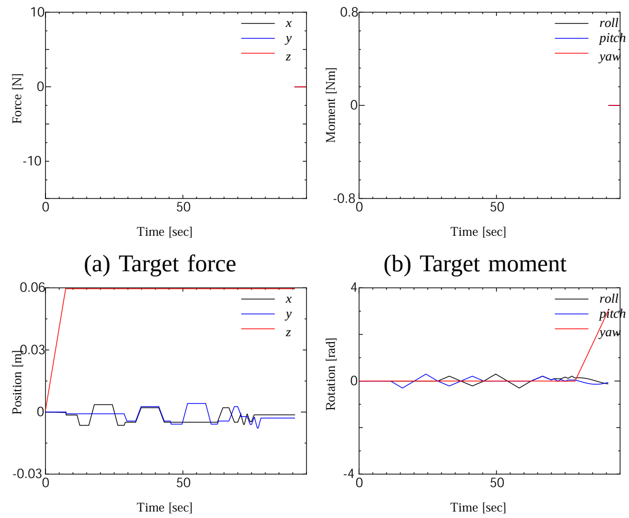
B. Circle Handle Valve Manipulation Task Skill

An overview of the circle handle valve (open and close) manipulation task is shown in Fig. 6. A manipulator has a parallel 2-finger hand. A circle handle valve is locked in the environment. A size of the valve is V40A.

Σ_h is the tip coordinate system of the manipulator with its origin in O. Σ_c is the base coordinate system with its origin set C at the center of the circle handle valve. In this task skill, Point O is set to a controlled point and is moved by the hybrid control in the task skill coordinate system (Σ_s) which is set by Σ_h. Σ_s is fixed in one point of the space and can be always reset by Σ_h. Thus, Σ_h moves with the hand, Σ_s does not move with the hand.

Here, as an initial condition, the permissible translation errors (for the x and y axes) of Σ_c are set one-quarter to the radius of the circle hand. The permissible orientation errors (for the roll and pitch axes) of Σ_c are set to 0.25 rad. The distance between Point O and Point C is set less than 0.1 m.

In this task, the operator performs the task using the parallel bilateral teleoperation system. The operator manipulates Point O using the master arm.

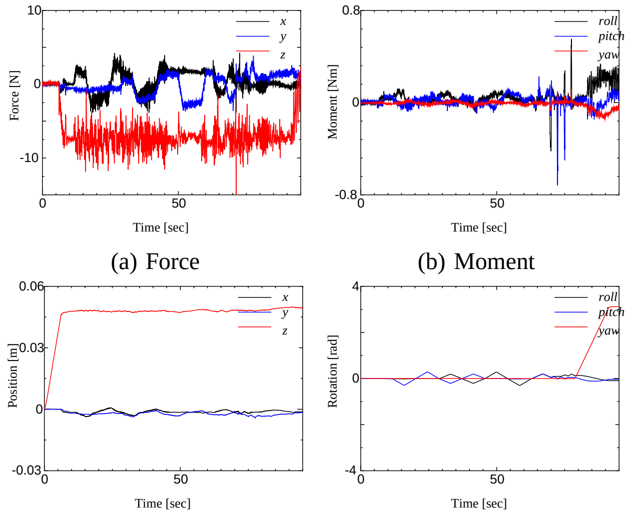


(a) Target force (b) Target moment

(c) Target position of impedance center

(d) Target rotation of impedance center

Fig. 4. Target data for bolt attachment task.



(a) Force (b) Moment

(c) Position (d) Rotation

Fig. 5. Experimental result of bolt attachment task.

Figure 7 shows a flowchart of the circle handle valve manipulation task skill procedure.

During the programming of this task skill, the operator used the V40A valve only. In order to demonstrate the robustness of the task skill, three size valves (V32A, V40A and V50A) are used.

We also prepare two type experiments. In (α) experiment, the robot closes the valve. In (β) experiment, the robot opens the valve by 4.71 rad. the same circle handle valve manipulation task skill is executed in (α) and (β).

Moreover, in order to demonstrate the robustness of the positional error, we prepare two type experimental environments. In (I) condition, the translation error is a few millimeters and the rotation error of Σ_c is zero. In (II) condition, the translation error is a few millimeters and the rotation error of Σ_c is 0.07 rad. Altogether, this experiment is thus carried out 12 times.

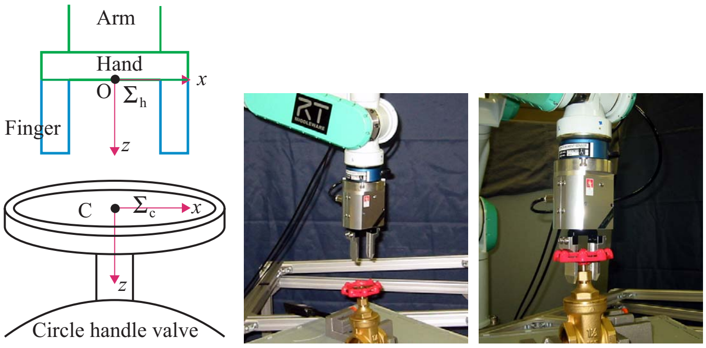


Fig. 6. Circle handle valve manipulation task.

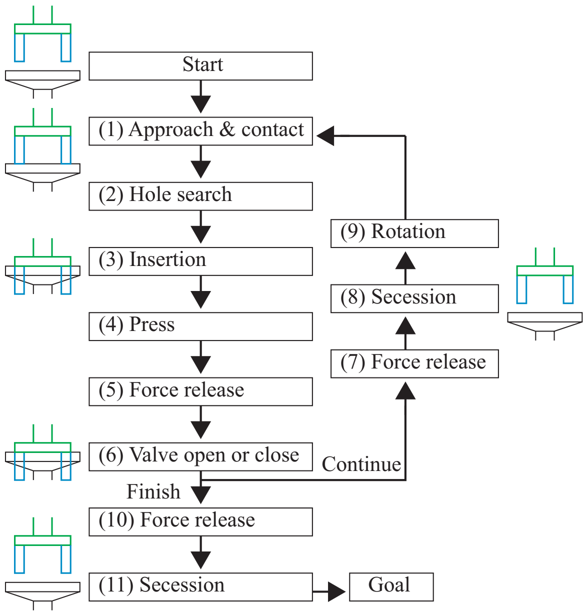


Fig. 7. Flowchart of a circle handle valve manipulation task skill procedure.

All of them were successful. As an example, the circle handle valve manipulation task which used V40A valve in (α) and (II) is shown in Fig. 9. A translation error and a rotation error can be observed in these figures.

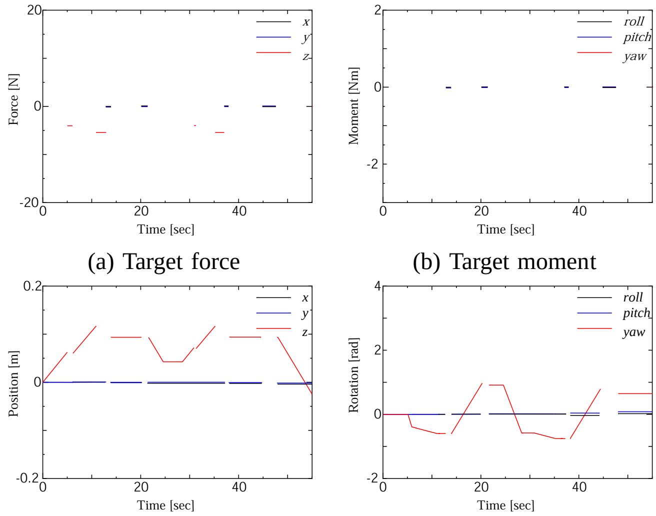
In (α) and (II), the procedure of this experiment is (1)∼(9), (1)∼(9), (1)∼(6), (10) and (11).

V. Task Skill Component for RT-Middleware

In this section, we discuss a task skill component for RT-Middleware.

In above section, we showed few task skills that are able to execute practical tasks. To use the task skill in RT-Middleware framework, we show a concept of task skill component in Fig. 10.

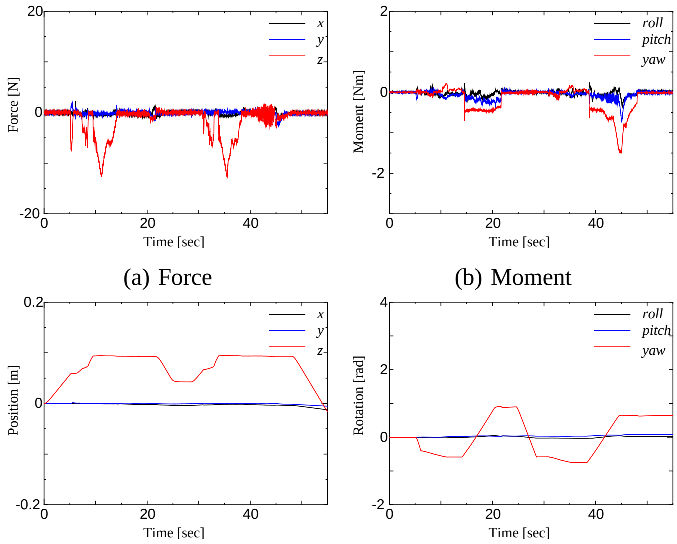
A robot system in Fig. 10 is the same as the task skill execution robot system in III. B. The low level control of a robot arm is a position control and the high level control is the hybrid impedance/force control. Inport data of robot system component are position of impedance center and target force. Outport data of robot system component are tip position and tip force. A task skill component is implemented by above task skill. In this architecture, it is easy to replace the task skill component.



(a) Target force (b) Target moment

(c) Target position of impedance center (d) Target rotation of impedance center

Fig. 8. Target data for valve close task.



(a) Force (b) Moment

(c) Position (d) Rotation

Fig. 9. Experimental results of valve close task.

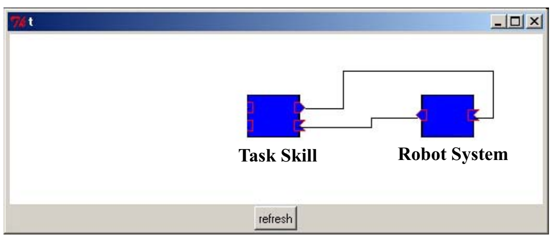


Fig. 10. Concept of task skill component.

VI. Conclusion

This paper described a requirement of task skill in a service field, and a few task skill studies using our task skill transfer method. To re-use the task skill easily, moreover, this paper commented on the need for task skill components for RT-Middleware.

We showed a bolt attachment task skill and a circle handle valve manipulation task skill. These task skills were generated by our task skill transfer method using a bilateral teleoperation. To use these task skills in RT-Middleware, we discussed a concept of task skill component.

In the future work, the task skill component will be executed in a real world.

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