An Intelligent Multipurpose Control Method Using Multifunctional Actuator

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***Abstract*—**
Multifunctional actuators are expected to be applied to humanoid robots, since these actuators are small, and have a lot of functions. However, they are difficult to use well in a multipurpose system. Since humanoid robots are a multipurpose system, this difficulty should be overcome. On the other hand, human can conduct multipurpose operation under various environments. In this paper, an intelligent multipurpose control method is proposed. This method is based on human's operation scheme. And, an intelligent multipurpose control system using multifunctional actuators is constructed based on the proposed method. The effectiveness of the proposed method was confirmed by experiments.

I. INTRODUCTION

Recently, concern for a humanoid robot has risen. A main purpose of these robots movement is a realization of a flexible movement in the same way as a human. However, this is very difficult to be achieved. Realization of a movement (Especially, running, and jumping) to need softness of joint becomes the main problem. Therefore, flexible and multipurpose control with which position and softness of the actuator are satisfied at the same time in the changing situation is necessary.

As for the method of softness of the joint so far, softness was given virtual by the position control of the actuator. In this method, there are some problems like as causing the delay in the motion control system. The motor controller for the small robot is developed to solve these problems, and the multifunctionalization of the actuator advances. In addition, an effectiveness of multifunctional actuators is shown by applying it to a small humanoid robot in specific operation. [1]. Therefore, the development of the humanoid robot control can be expected using a multifunctional actuator. However, a multipurpose control (to satisfy a position, softness, and output torque at the same time) of the multifunctional actuator is difficult since a multifunctional actuator coordinates the softness by changing its characteristics.

On the other hand, the research on human operation has been done so far [2][3]. And human's operation control scheme has been clarified. Thus, its scheme is expected to be built into robots.

In this paper, constructing an intelligent multipurpose control system using multifunctional actuators is aimed. The method to construct such control system is proposed by by focusing on human's operation control scheme. And the effectiveness of the proposed method is confirmed by experiments.

II. MULTIFUNCTIONAL ACTUATOR

A. Composition of multifunctional actuator

A multifunctional actuator is an actuator module which is equipped with a motor, some sensors, a micro controller unit(MCU), and else. A composition of multifunctional actuator is shown in Fig. 1. A multifunctional actuator can produce the motor's temperature and the present position etc. of the actuator to the user in accordance with the command instructed by the host computer. It can give softness to the output by changing its own proportion control gain. In case of a past single functional actuator, the load to the user's control of the actuator is large, since it makes the user do the design of the control machine and the equipment of the sensor, etc. On the other hand, in case of multifunctional actuator, it can let a user more easily perform complicated control because of dividing the role on the host side and the actuator side. Based on these reason, a multifunctional actuator is effective for the field of the robot from which a complex control is demanded.

The characteristic of position-torque of the multifunctional actuator is shown in Fig. 2. The softness of the actuator is arbitrarily set by a compliance slope shown in Fig. 2. If this width is widely taken, it becomes a soft output since the proportion gain becomes small. In this paper, the width of compliance Slope is defined as the softness of the actuator. The output torque value at a certain position is controlled by the target position (It is described later as an actuator target in this paper) and the softness of the actuator. The vector (softness , output torque value) with the elements of the softness and the output torque value is described as a torque characteristic value in this paper.

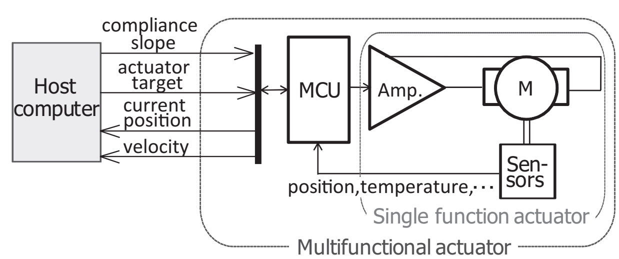

Fig. 1. Composition of a multifunctional actuator

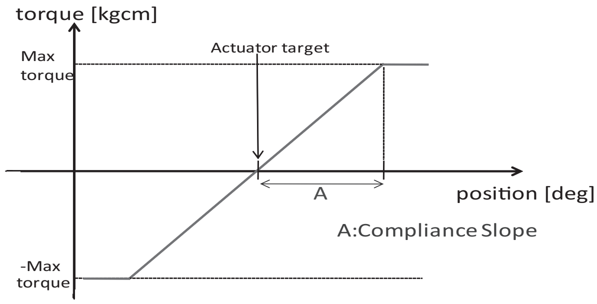

Fig. 2. Relationship between the position and torque

B. Characteristic of an multifunctional actuator

Because the multifunctional actuator can let a user more easily perform complicated control, use as the actuator for the joint drive of the robot can be expected. However, the multifunctional actuator is difficult to use as a multipurpose device, because it performs positioning in the user's arbitrary proportion gain. For example, there is the case of cannot achieve the actuator target when the softness of the actuator becomes higher.

Driving data of a multifunctional actuator (made of Futaba RS302CD) is shown in Fig. 3. The control purpose of this time is purpose position = 50 [deg], output torque value (at the purpose position) = 0[kg/cm], softness = 80[deg]. In order to satisfy the torque characteristic value which is aimed for, a set value to the actuator is 50 [deg] of the actuator target and 80 [deg] of the compliance slope. However in this case, it is driven from 0 degrees at an initial position to only 40 [deg]. The cause that cannot be driven to a target position is that the proportion control gain of the actuator is small. Since such phenomenon becomes a problem in the robotic control, a multipurpose control of a multifunctional actuator that satisfies the position and the torque characteristic value at the same time is necessary.

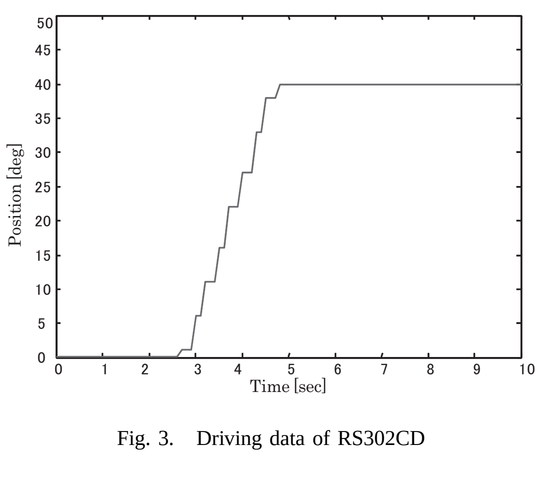

Fig. 3. Driving data of RS302CD

III. Intelligent multipurpose control method

Human has achieved a flexible and multipurpose operation under various environments. In this chapter, the human's motion control method is focused, and the intelligent multipurpose control method which is based on their method is proposed. In addition, the control system is designed based on the proposal method.

A. Human's motion control method

To know the method which is adjusting the viscoelasticity and the joint angle of the joint by human is an important factor and problem for developing a humanoid robot [4]. Up to present, there is much examination concerning human's motion control method. For example, an examination about the movement of human arm. In these studies, it is made clear that the human adjusts viscoelasticity predictively. And it is made clear that the human improves the adjustment by learning in a multiple trial. However, a human's concrete motion control method has not been clarified yet. Understanding from these results is that a human has a musculoskeletal system model, and a updatable mental model which is provided by interaction with the environment. Plus, human is doing the forecast and the control by using these models. Therefore, the achievement of the multipurpose control can be expected by building these model and control knowledge into the controller.

In the situation without an external interaction with the environment, human need not learn. In such a situation, human's musculoskeletal system model has been established, and it does not need to update.

Therefore, the model's update by learning is not considered in the present study, and realization of the multipurpose control in the situation without external interaction is aimed at. To achieve this purpose, the model of the control object and the control knowledge are built into the controller.

B. Construction of the controller

In this study, the model of the controlled object and the control knowledge are built into the controller using a predictive fuzzy control. The predictive fuzzy control is a control method which predicts the future state of the controlled object, and selects the control instruction by evaluating the predicted result [5]. There is a fact that human also controls its movement predictively. Therefore, this control method is suitable for the intelligent multipurpose control that is aimed in this paper.

The inference process by the predictive fuzzy control is to achieve the multipurpose control of a multifunctional actuator is shown in Fig. 4. U is a candidate of the control instruction composed of the actuator target (AT) and compliance slope (CS).

Current position, and +-1 [deg] from current position are the candidates of AT. And current CS, and +-1 [deg] from current CS are candidates of the CS.

There are nine candidates of the control instruction. All the combinations (nine kinds) of these each candidates are candidates of the control instruction. All these instruction candidates are evaluated by the fuzzy inference based on the control rules, and the control instruction candidate with the highest evaluation is instructed in to the actuator as a control instruction. Human's control methodology are described as control rules by using DO-if rule [6][7]. Control rules are shown as follows

- Do U is $C1[AT_{old}, CS_{old}]$ if error with the target position (X_e) is good and error with the target torque characteristic value (T_e) is very good.

- Do U is $C2[AT_{old} + 1.0[deg], CS_{old}]$ if error with the target position (X_e) is very good and error with the target torque characteristic value (T_e) is very good.

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- Do U is $C9[AT_{old} - 1.0[deg], CS_{old} - 1.0[deg]]$ if error with the target position (X_e) is very good and error with the target torque characteristic value (T_e) is very good.

AT_{old} and CS_{old} are last instruction, X_e is a difference of a future position and a target position, and T_e is a difference of a future torque characteristic value and a target torque characteristic value. And T_e is vector $[S_e, O_e]$. S_e is a difference of the target softness and the instruction candidate's softness. O_e is a difference of the target output torque value and the future output torque value. When the control purpose is changed, AT_{old} and CS_{old} become target position and target softness regardless of the last instruction. Since such a control rule exists for the candidates of all the control instructions, the candidates of the control instruction with the highest evaluation is finally chosen as a control instruction.

A fuzzy set to evaluate the error of the position is shown in Fig. 5, and a fuzzy set used to evaluate the error of the torque characteristic value is shown in Fig. 6. The set shown in figure 5 shows that the difference of the target position and the future position is very good. Therefore, when the difference of the target position and future position is 0, μ will become the maximum 1. This μ is an evaluation value to X_e. The set shown in figure 6(a) shows that S_e is very good, and the set shown in figure 6(b) shows that O_e is very good. Mean value of evaluation value obtained from (a) and (b) is an evaluation value to T_e.

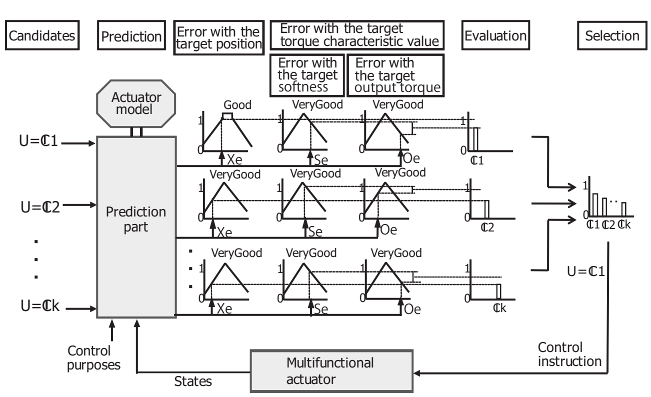

Fig. 4. Inference process of the controller

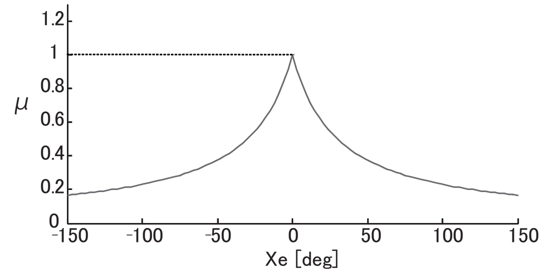

Fig. 5. Fuzzy set used to evaluate a purpose of the position

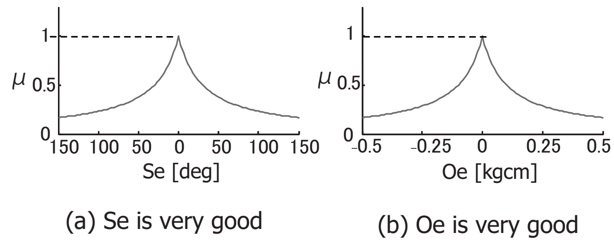

Fig. 6. Fuzzy set used to evaluate a purpose of the torque characteristic value

IV. Composition of the System

The composition of the multipurpose control system using the multifunctional actuator is shown in Fig. 7. The controller into which the model of the control knowledge and the controlled object is an intelligent multipurpose controller. The controlled object is a multifunctional actuator (made of Futaba RS302CD) which is equipped with the 12mm servo horn. The model is changed based on the state in the present position etc. of a multifunctional actuator, and future states of the controlled object are predicted by using this variable model. The control instructions are evaluated and selected by a fuzzy multipurpose evaluation using the predicted results, and it is transmitted to the actuator. Evaluation and selection of the control instructions by the intelligent multipurpose controller is performed every 0.1 seconds, and only when a control instruction different from the last control instruction is selected, it is transmitted to the actuator.

V. Experiment

To confirm the effectiveness of the proposed intelligent multipurpose control method, experiments by using the constructed system were performed. The appearance of experiments is shown in Fig. 8. The multifunctional actuator (Futaba RS302CD) with the 12[mm] servo horn is a controlled object. The state of the actuator obtained from it is displayed in the monitor. The softness etc. of the actuator can be confirmed through this monitor. In experiment 1, the comparison experiment with the data shown in Fig. 3 in Chapter 2 is conducted. In experiment 2, to verify the flexibility of the system, the experiment that changes control purposes is conducted.

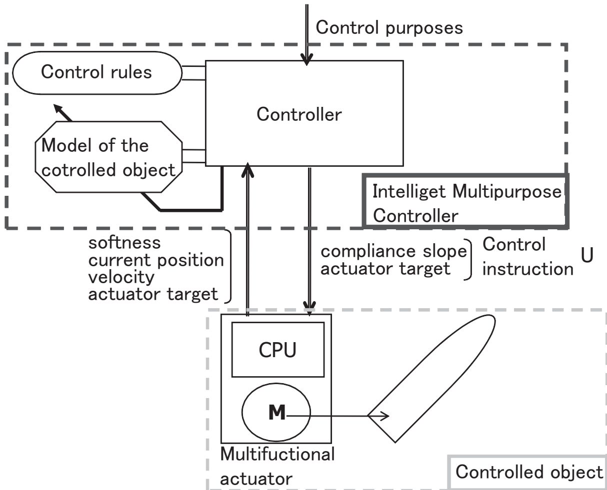

Fig. 7. Composition of the system

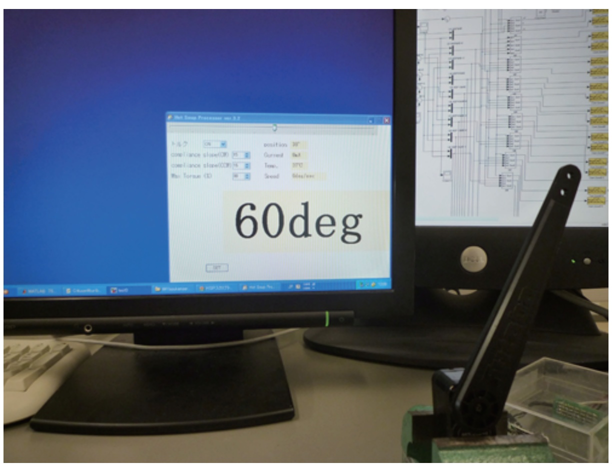

Fig. 8. Appearance of experiments

A. Experiment 1

Experiment 1 is an experiment to compare the result by the proposal method with the result shown in Fig. 3. Control purpose in experiment 1 is the same as the purpose used in Chapter 2. It is shown below.
{Purposes} target position:50[deg], softness:80[deg], output torque value:0[kg-cm](at the target position).
Results of experiment 1 are shown in Fig. 9,10,11. The data shown in Fig. 9 is a transition of the servo horn position, the data shown in Fig. 10 is a transition of the actuator target, and the data shown in Fig. 11 is a transition of the actuator's softness. The servo horn position finally became 48[deg]. Actuator target rose from 50[deg] to 58[deg], and became 50[deg] finally afterwards. Softness of the actuator was dropped from 80[deg] to 76[deg], and became 80[deg] finally afterwards.

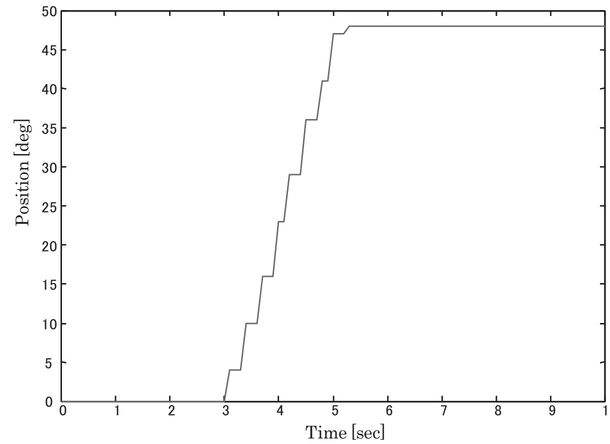

Fig. 9. Time history of the position of the actuator

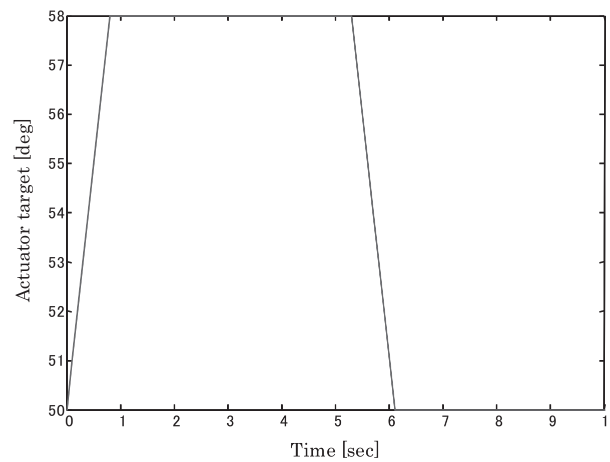

Fig. 10. Time history of the actuator target

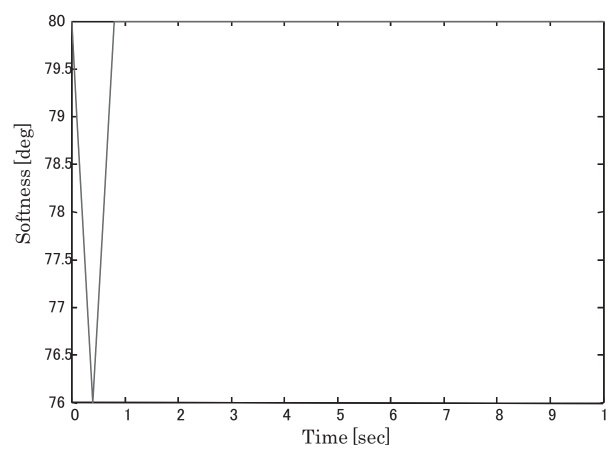

Fig. 11. Time history of the softness

B. Experiment 2

Experiment 2 is an experiment to verify whether the proposal method can flexibly correspond to the purpose change. In experiment 2, two control purposes (purposes 1 and purposes 2) are given. After purposes 1 are given; 7 seconds later, control purposes are changed from purposes 1 to purposes 2. Control purposes of this experiment are shown below.

{Purposes 1} target position:30[deg], softness:30[deg], output torque value:0[kg-cm](at the target position)

{Purposes 2} target position:60[deg], softness:90[deg], output torque value:0[kg-cm](at the target position)

Results of experiment 2 are shown in Fig. 12,13,14. The data shown in Fig. 12 is a transition of the servo horn position, the data shown in Fig. 13 is a transition of the actuator target, and the data shown in Fig. 14 is a transition of the actuator's softness. The servo horn position finally became 28[deg] in purposes 1, and it finally became 58[deg] in purposes 2. Actuator target finally became 30[deg] in purposes 1, and it finally became 60[deg] in purposes 2. Softness of the actuator finally became 30[deg] in purposes 1, and it finally became 90[deg] in purposes 2.

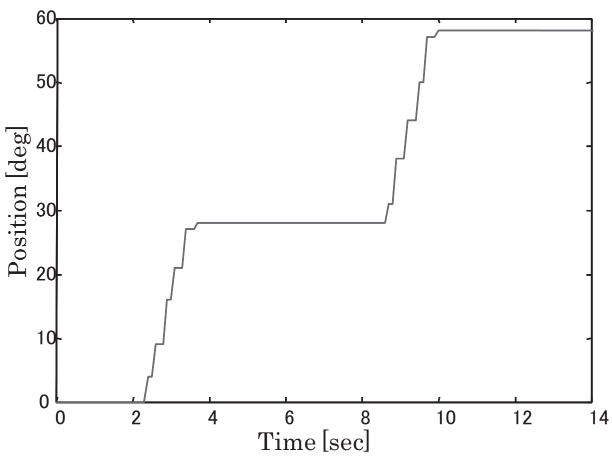

Fig. 12. Time history of the position of the actuator

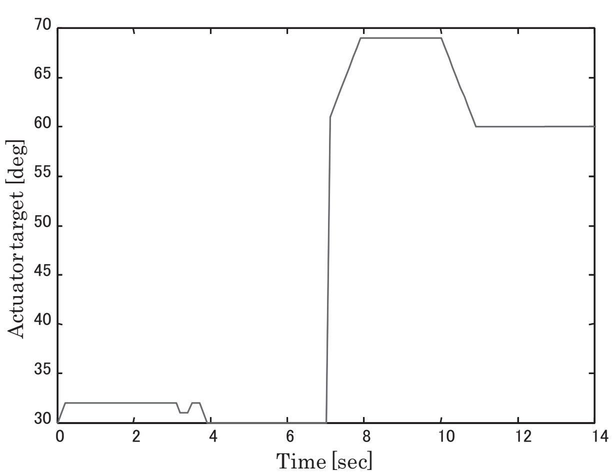

Fig. 13. Time history of the actuator target

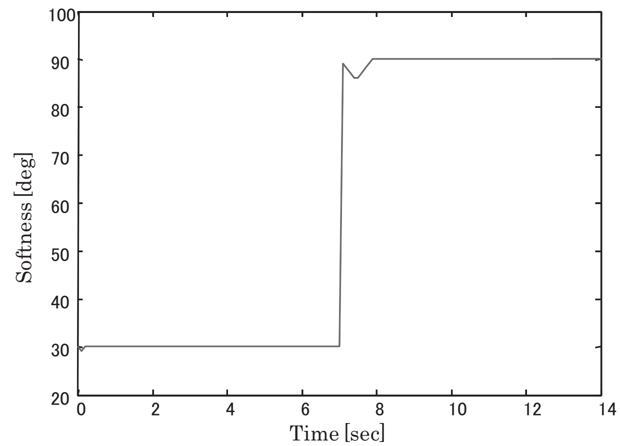

Fig. 14. Time history of the softness

C. Consideration

At experiment 1, in order to satisfy a target position, it is necessary to make the servo horn's position reach almost 50[deg] as much as possible. And in order to satisfy a target torque characteristic value, it is necessary to make actuator target and softness reach almost 50[deg] and 80[deg] as much as possible. In a result which was shown in Fig. 3, a final position was 40 [deg] though target characteristic value was satisfied completely. The error of the target position and final position was 20%. On the other hand, in the proposal method(Fig. 9,10,11), a final position was 48[deg]. The error of the target position and the final position was 4%. Also about torque characteristic value, finally it was satisfied completely, though the maximum error of 16In this study that paid attention to human's control strategy, the purposes are considered as good when these were satisfied to some extent. Therefore, these results can be considered as control purposes were satisfied well.

At experiment 2, in the case of purposes 1, in order to satisfy a target position, it is necessary to make the servo horn's position reach almost 30[deg] as much as possible. And in order to satisfy a target torque characteristic value, it is necessary to make actuator target and softness reach almost 30[deg] and 30[deg] as much as possible. In the case of purposes 2, in order to satisfy a target position, it is necessary to make the servo horn's position reach almost 60[deg] as much as possible. And in order to satisfy a target torque characteristic value, it is necessary to make actuator target and softness reach almost 60[deg] and 90[deg] as much as possible. In purposes 1, the error of the target position and the final position was 6.7%. And in purposes 2, the error of the target position and the final position was 3.3%. Target position was satisfied well in both purposes. Also about torque characteristic value, in both purposes, finally it was satisfied completely, though the maximum error of 15The size of this error can be adjusted by a fuzzy set and the control knowledge. It was judged that this error was able to be allowed by the intelligent multipurpose controller. Therefore, these results can be considered as control purposes were satisfied flexibly.

VI. Conclusion

In this paper, constructing the intelligent multipurpose control system by building human's operation control scheme into the controller was aimed. The intelligent multipurpose control method using a multifunctional actuator was proposed, and the intelligent multipurpose control system was constructed with the proposed method. The actuator's behavior and the transition of set value was examined by experiments. And as a result, it was confirmed to be able to achieve a multipurpose control that both the position and the torque characteristic value [softness, output torque value] were satisfied. An intelligent multipurpose control using multifunctional actuators was able to be achieved by the proposed method.

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