Control of a Robot Handling an Object in Cooperation with a Human

Kazuhiro KOSUGE   Norihide KAZAMURA

Department of Machine Intelligence and Systems Engineering
Tohoku University
Aza-Aoba, Aramaki, Aoba-ku
Sendai 980-77, Japan

Abstract

We consider a robot system handling an object in cooperation with a human, with which the human can easily handle a heavy object. The robot system supports and moves the object in the direction of the intentional force applied to the object by the operator. We discuss how to generate the motion of the object based on the intentional force applied to the object by the human. We propose several algorithms to generate the motion based on the intentional force and experimentally compare them.

1 Introduction

With the development of robot technologies, robots have been applied to many fields as industrial robots. Most of these robots, however, have been isolated from humans and have been used as a programmable machine for the execution of a preprogrammed single task. If a robot could execute tasks in cooperation with a human, a robot could be used in our day life for home automation, office automation, medical application and so on.

Several researchers have considered the control problem of a robot system handling an object in cooperation with a human or humans. Kazerooni et al. proposed a control system for a human extender with which the human power is amplified so that the human can handle a heavy object [1]. Kosuge et al. proposed an impedance control system for a human power amplification [2]. Kosuge also proposed an impedance based control algorithm for multiple robots handling a single object in cooperation with humans [3]. Ikeura et al. proposed a control system based on human impedance characteristics [4]. Y. Zheng considered a load-sharing problem for a robot handling an object together with a human [5] [6].

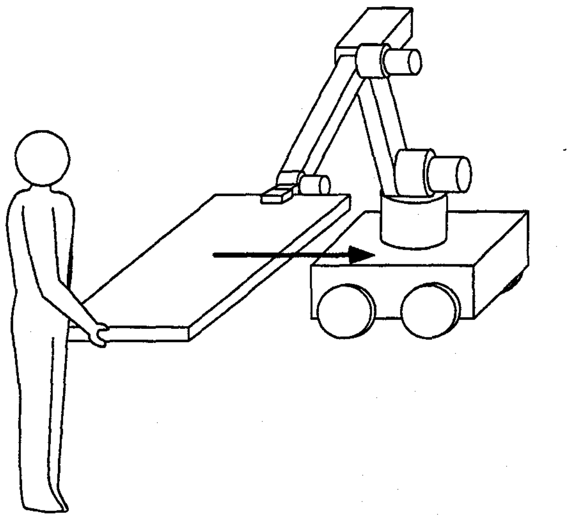

Figure 1: Human-Robot Cooperation

In this paper, we consider a control system for a robot handling an heavy object in cooperation with a human. The robot supports and moves the object in the direction of the intentional force applied to the object by the operator. In the followings, we discuss how to generate the motion of the object based on the intentional force applied to the object by the human, which is one of the key issues for the control of the robot. We propose several algorithms for the motion generation problem of the robot based on the operator's intentional force. We then do the comparative study of the algorithms.

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2 Human-Robot Cooperation System

Let us consider a robot system handling an object in cooperation with an operator as shown in fig. 1. In this system, the operator applies his/her intentional force to the object supported by the robot in the direction along which the operator would like to move the object. That is, the robot supports the weight of the object, and the operator can easily manipulate the object by applying only the intentional force to the object.

In this paper, for the simplicity of discussions, we assume that the robot and the operator have interaction each other only through the manipulated object as illustrated in fig. 2. For realizing such a robot system, we have to consider several problems, such as the stability of the resultant system including human dynamics, manipulability of the object and so on .

Kosuge proposed a control system based on the impedance control of the manipulated object for multiple robots handling an object in cooperation with humans and proved the stability of the resultant system from the passivity point of view [7]. Since the stability of the resultant system is guaranteed as long as the passivity of the apparent dynamics of the object is preserved, other control algorithms, which also guarantee the stability of the resultant system, may be more appropriate for the system from the object maneuvering point of view. In the following part of this paper, we consider how to generate the motion of the object based on the intentional force applied to the object by the operator from the object handling point of view.

3 Motion Generation of Object Based on Intentional Force

In this section, we consider how to generate the motion of the object based on intentional force. Several methods could be considered for the motion generation the object based on intentional force as follows:

(1) Method of Force Augmentation Type
This is a method originally proposed for a human extender [1] or a human amplifier [2]. To handle the object, the robot is controlled so as to generate force proportional to the operator's intentional force.

(2) Method of Position Control Type
This method controls the relation between the position of the object and the operator's intentional force. The stiffness control is one of the typical control algorithms of this category.

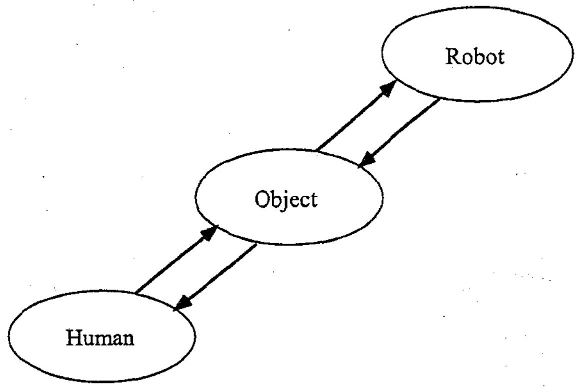

Figure 2: Relation among Human and Robot

(3) Method of Velocity Control Type
This method controls the relation between the velocity of the object and the operator's intentional force. The damping control is one of the typical control algorithms of this category.

(4) Method of Acceleration Control Type
This method controls the relation between the acceleration of the object and the operator's intentional force. The impedance control is one of the typical control algorithms of this category.

Let us consider which methods are suitable for the human-robot cooperation for handling an object. We would like to design a system so that we can handle the object by applying intentional force only, or the object must not move without applying the intentional force for the handling the object.

Among above mentioned types of control methods, (1) and (2) requires an operator to support a part of the weight of the object. Since it may be tough for a human operator to support even a part of the weight of the object during the manipulation, we are going to consider the case (3) and (4) in the following part of this paper. In the following part of this paper, we are going to consider typical and fundamental algorithms for case (3) and case (4), although many algorithms could be considered for the case (3) and the case (4).

In case (3), the velocity of the object is generated based on the intentional force. As a typical example of the algorithms of case (3), we consider to generate the velocity of the object based on the intentional force as

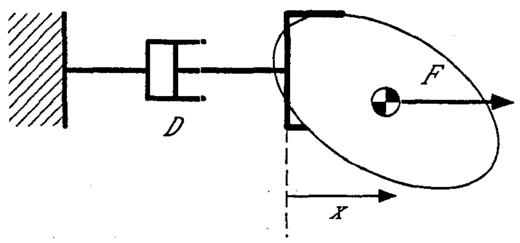

Figure 3: An Example of Damping Control

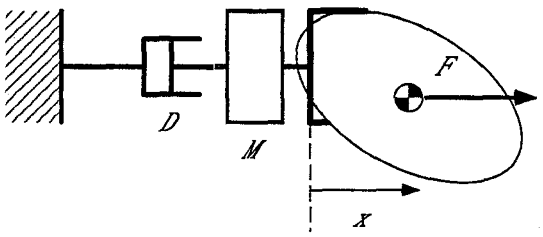

Figure 4: An Example of Impedance Control

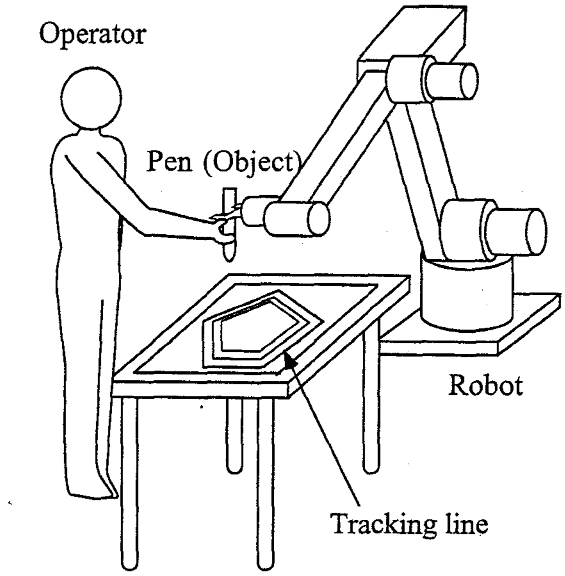

Figure 5: Experimental Human-Robot Cooperation System

shown in fig. 3 by the following equation:

$$F = D\dot{x} \tag{1}$$

where,

$\dot{x}$: velocity of the manipulated object.
D : damping coefficient matrix.($D > 0$)
F : intentional force applied to the object.

In case (4), the acceleration of the object is generated based on the intentional force. As a typical example of case (4), we consider the impedance control of the manipulated object as shown in fig. 4 by the following equation:

$$F = M\ddot{x} + D\dot{x} \tag{2}$$

where,

$\ddot{x}$: acceleration of the manipulated object.
$\dot{x}$: velocity of the manipulated object.
M : inertia matrix.($M > 0$)
D : damping coefficient matrix.($D > 0$)
F : intentional force applied to the object.

In the following section, we apply these methods to experimental manipulation system. We compare them and consider which methods are suitable for the human-robot cooperation.

Table 1: Parameter List for Experiment

No.	Control method	d $[Ns/m]$	m $[kg]$
1	Damping	100	—
2	Impedance	100	5
3	Impedance	100	10
4	Damping	50	—
5	Impedance	50	5
6	Impedance	50	10

4 Experiment

4.1 Experimental System

We do experimental study for the case (3) and the case (4) using an industrial robot having six degrees of freedom. The six-axis force/torque sensor is attached to the wrist of the robot and is used to measure the intentional force applied to the manipulated object. An Intel Pentium Processor(166MHz) is used to control the manipulator. The control algorithm is implemented using a real time operating system VxWorks. The sampling rate is 1000 Hz.

4.2 Experimental Method

The robot is controlled so as to have the apparent dynamics expressed by eq. (1) or (2) using the VIM [8]. We compare the maneuvering performance of the

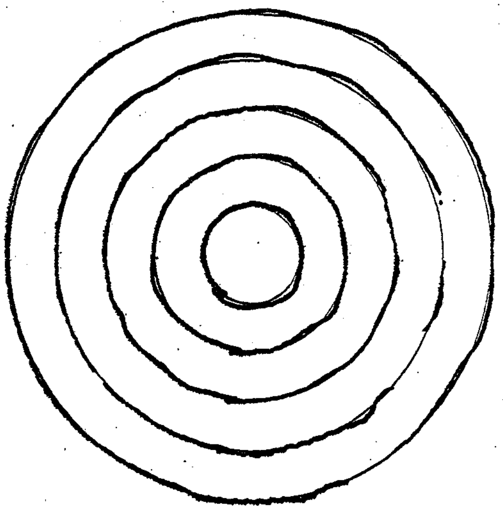

Figure 6: Experimental Results(circle)—Damping control $d = 50$ $[Ns/m]$

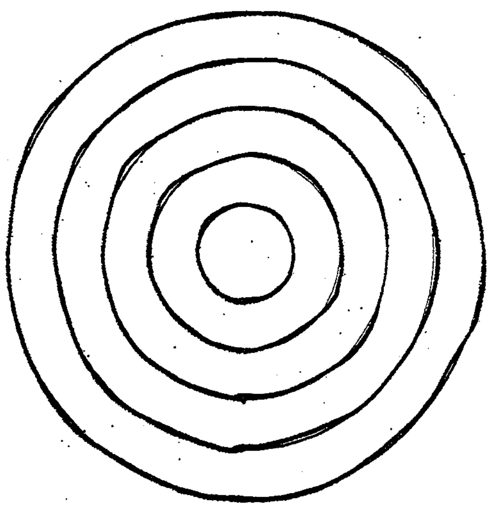

Figure 8: Experimental Results(circle)—Impedance control $m = 10$ $[kg], d = 50$ $[Ns/m]$

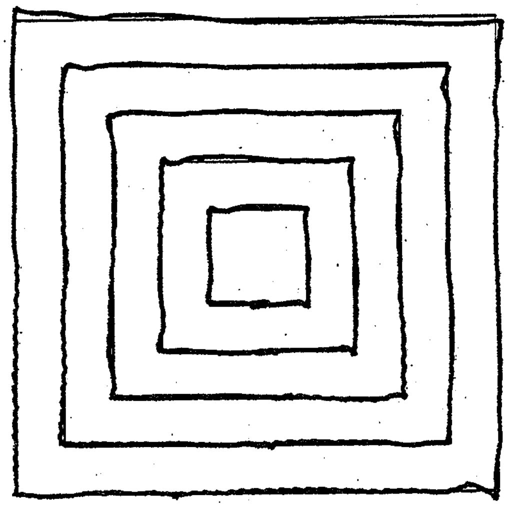

Figure 7: Experimental Results(square)—Damping control $d = 50$ $[Ns/m]$

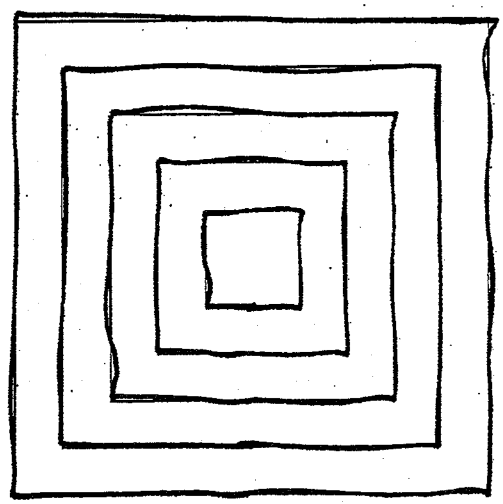

Figure 9: Experimental Results(square)—Impedance control $m = 10$ $[kg], d = 50$ $[Ns/m]$

case (3) and the case (4) by asking several people to grab the pen attached to the end of the manipulator and to trace two types of drawings, squares and circles with different dimensions, drawn on a sheet of paper by applying intentional force to the pen. We also asked them to give comments on the maneuvering performance. In the experiments, the orientation of the pen is kept constant and only translational motion is generated according to the dynamics expressed by eq. (1) or (2).

The parameter matrices D and M are selected as diagonal matrices having the same diagonal elements as follows:

$$\begin{aligned} D &= dI \\ M &= mI \end{aligned}$$

where, I is a 3×3 identity matrix.

4.3 Results

The parameters used in the experiments are shown in the table 1. As shown in the table, six types of experiments were carried out. The experiments are classified into two types; one is the experiments with a high damping coefficient and the other one is the experiments with a low damping coefficient.

Some of the experimental results are shown in figs.6 $\sim$ 9. The intentional force applied to the pen during the experiments are also shown in figs. 10 $\sim$ 13. The followings are the summaries of the comments received form the people, who executed the line tracing experiments for both the case (3) and the case (4).

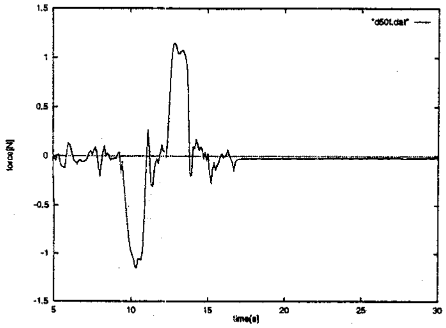

Figure 10: Intentional force(smallest square, x–axis, $d = 50$)

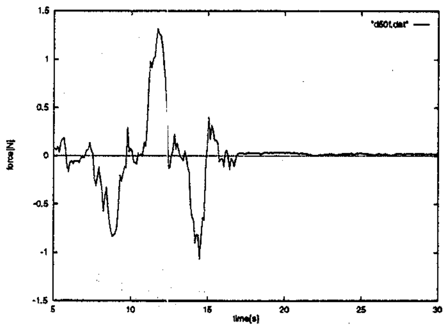

Figure 11: Intentional force(smallest square, y–axis, $d = 50$)

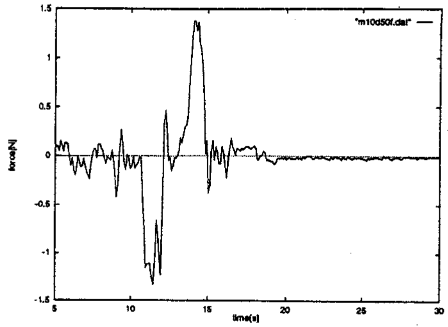

Figure 12: Intentional force(smallest square, x–axis, $m = 10$, $d = 50$)

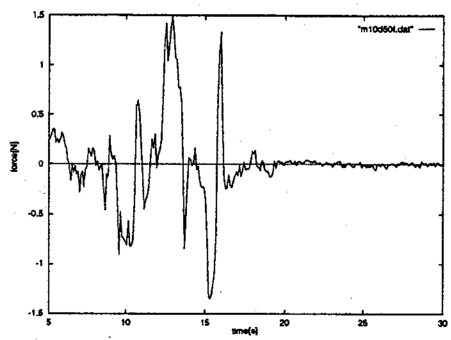

Figure 13: Intentional force(smallest square, y–axis, $m = 10$, $d = 50$)

4.3.1 Results with high damping coefficient

The damping coefficient of this case was $d = 100$[Ns/m]. In this case, the motion of the robot was relatively slow and took a relatively long time to finish tracing a drawing. We had the following comments:

- The operator could trace drawings in a stable manner for the impedance control case (4).
- The motion was a bit shaky for the damping control case (3).
- The easiness of maneuvering of the pen is almost the same for both cases. Large differences could not be seen in the results of line tracing for both cases.

4.3.2 Results with low damping coefficient

The damping coefficient of this case was $d = 50$[Ns/m]. In this case, the motion of the robot was fast and tracing of a drawing was finished in a short time. We had the folowing comments:

- The operator could smoothly trace a line or a circle in a stable manner for the impedance control case (4), however it was difficult to trace the corner of the square without overshoot.
- The tracing motion of a line or a circle for the case of the damping control was jagged although the stability of the system was not lost. However, it was not difficult to trace the corner of a square without overshoot.

4.4 Discussions

In the case of the damping control, external forces such as friction force applied to the pen easily affects the motion of the object, since the external force is directly related to the velocity of the motion. This reduced the smoothness of the motion, while made it easy to trace a sharp corner.

In the case of the impedance control, the tracking of a line or a circle was easily and smoothly done without the effect of the external disturbances even for a low damping coefficient, because the effect of the disturbances was reduced by the inertia term. The large inertia term made it difficult to trace a sharp corner without overshoot.

With the low damping coefficient, the operator could trace the line with smaller intentional force compared to the high damping coefficient case. Each control method has its own merit and demerit. As a result, the impedance control with a low damping coefficient and an appropriate inertia coefficient is better than the damping control case.

5 Conclusion

In this paper, we considered the motion generation problem of a robot system handling an object in coordination with humans. We discussed four types of methods, which include force augmentation type, position control type, velocity control type and acceleration control type. For the velocity control type or the acceleration control type, we carried out experiments and compared the performance from the object maneuver point of view. As an example of the acceleration control type, we implemented a kind of impedance control. As a result, the impedance control with a low damping coefficient is better than the damping control case.

Acknowledgments

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References

[1] H.Kazerooni, "Human Machine Interaction via the Transfer of Power and Information Signals" *Proceedings of IEEE International Conference on Robotics and Automation*, pp. 1632-1642, 1989.

[2] K.Kosuge, Y.Fujisawa, T.Fukuda, "Control of Robot Directly Maneuvered by Operator" *IEEE International Conference on Robots and Systems*, pp. 49-54, 1993.

[3] K.Kosuge, H.Yoshida, T.Fukuda, "Dynamic Control for Robot-Human Collaboration" *IEEE International Workshop on Robot and Human Communication*, pp. 398-401, 1993.

[4] R.Ikeura, H.Monden, H.Inooka, "Cooperative Motion Control of a Robot and a Human" *IEEE International Workshop on Robot and Human Communication*, pp. 112-117, 1994.

[5] O.M.Al-Jarrah, Y.F.Zheng, "Arm Manipulator Coordination for Load Sharing Using Variable Compliance Control" *Proceedings of IEEE International Conference on Robotics and Automation*, pp. 895-900, 1997.

[6] O.M.Al-Jarrah, Y.F.Zheng, "Arm Manipulator Coordination for Load Sharing Using Reflexive Motion Control" *Proceedings of IEEE International Conference on Robotics and Automation*, pp. 2326-2331, 1997.

[7] K.Kosuge, H.Yoshida, D.Taguchi, T.Fukuda, "Robot-Human Collaboration for New Robotic Applications" *Proceedings of IEEE IECON*, pp. 713-718, 1994.

[8] K.Kosuge, K.Furuta, T.Yokoyama, "Virtual Internal Model Following Control System — Application to Mechanical Impedance Control —" *Transactions of the Society of Instrument and Control Engineering*, Vol.24, No.1, pp. 55-62, 1988.

[9] K.Kosuge, "Classification of Force Control and Design of Control System" *Jounal of the Robotics Society of Japan*, Vol.9, No.6, pp. 751-758, 1991.

[10] J.K.Salisbuly, "Active Stiffness Control of a Manipulator in Cartesian Coordinates" *Proceedings of the 19th IEEE Conference on Decision and Control*, pp. 95-100, 1980.

[11] D.E.Whitney, "Force Feedback Control of Manipulator Fine Motions" *Transactions of ASME, Journal of Dynamic Systems, Measurement and Control*, June 1977, pp. 91-97, 1977.

[12] N.Hogan, "Impedance Control Part 1–Part 3" *Transactions of ASME, Journal of Dynamic Systems, Measurement and Control*, Vol.107, pp. 1-24, 1985.