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The Study of The Human Assist Manipulator Based on Position Control

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Abstract. The purpose of this study is to develop a hand guide system for the industrial manipulator. This manipulator moves to assist the operator by operator's command given to the handle attached to the tip of the manipulator. This kind of systems requires high safety measures. We focus on giving flexibility to the manipulator by control. However, in order to develop such a manipulator, we need development of the hand guide system of the manipulator which can incorporate a new control is necessary. In this research, we first develop the hand guide system manipulator which will be base of the manipulator that incorporates new control. The developed manipulator measures the command force by the force sensor attached to the tip of manipulator. Then, the command force acts as the commanded velocity. Also, the manipulator can change the rigidity of the tip. The assistance power can be arbitrarily changed according to the work of the operator.

1. Introduction

Many industrial robots have been used inside of safeguards from the viewpoint of safety. In recent years, a collaborative work of operator and robot has been recognized due to improvement of technology to safety, and industrial robots for that have come to be commercially available. One of the collaborative robots is the hand guide robot. In such a robot system, an operator moves the robot's hand in the motion range so that the robot follows the robot to assist the operator (Fig 1).

Fig. 1. The hand-guide manipulator

The collaborative robot exists in the same space as a person. Therefore, advanced safety measures are required to prevent operator from getting hurt. As a safety device of a robot currently on the market, there is a robot which stops its operation by detecting that the operator touched the robot. However, in a situation where the robot and the person actually move close to each other, there is a danger in a case where a person is hit by the robot just by stopping. Therefore, it is necessary to take further measures to prevent human injury. Industrial robots currently equipped with such technology are actively researched [1]. However, industrial robots that have flexibility in structure and joints have not been put to practical use yet, so the development of industrial robots having such a structure is awaited.

In this research, we focused on giving flexibility to the manipulator by controlling robots that assist operator. In developing such a robot, it is necessary to develop an actual machine capable of incorporating new control. Therefore, in this research, as a preliminary step of the development of flexible robot in the joint part, we will develop three-joint-robot which works to assist operators as the base to incorporate the control (After here, the three-joint-robot to be developed is called a manipulator).

A handle with a force sensor and an enabling device is attached to the tip of the manipulator, and the operator holds the handle and carries out work. At that time, the force sensor detects the force vector applied to the tip by the operator. The detected force vector is dealt as the velocity command vector. The motors attached to each joint are controlled by the velocity command vector with respect to the distal end portion.

2. Structure of the controller

The controller designed in this research follows the movement of the operator's work and the manipulator assists the operation of the operator. Further, it has a structure which can arbitrarily change the assisting force according to the operating situation. The motor is controlled by position control. This is because the robot to be developed in this research is for industrial use and it is structured to be able to add functions when positioning is necessary in work. The following is a step-by-step explanation from the time when the operator gives a command to the time when the arm operates. Here, the effect of gravity on the manipulator is not considered in controller.

At time t, an operator applies force to the handle on the arm tip. The force is measured as a force sensor with a force vector $\overrightarrow{\boldsymbol{F}_F}(t)$ ((t) represents time). In this research, $\overrightarrow{\boldsymbol{F}_F}(t)$ is dealt as the operator's velocity command $\overrightarrow{\boldsymbol{V}_O}(t)$. Controller is performed so that the velocity of the arm tip follows the velocity command.

As described above, since the control of the motor is performed using the position control, considering the gain k giving the assisting force arbitrarily, the target hand position $\overrightarrow{\boldsymbol{q}_T}(t+\Delta t)$ after one sample time Δt is expressed by the following equation using the velocity command $\overrightarrow{\boldsymbol{V}_O}(t)$ and the current hand position $\overrightarrow{\boldsymbol{q}_F}(t)$ (Eq. (1)).

$$\overrightarrow{\boldsymbol{q}_T}(t+\Delta t) = \overrightarrow{\boldsymbol{q}_F}(t) + k \cdot \overrightarrow{\boldsymbol{V}_O}(t) \cdot \Delta t \tag{1}$$

Here, $\overrightarrow{\boldsymbol{q}_F}(t)$ is obtained using the forward kinematics $\boldsymbol{f}(\theta_1, \theta_2, \theta_3)$ from each joint angle $\theta_{i(t)}$ (i = 1,2,3) at time t (Eq. (2)).

$$\overrightarrow{\boldsymbol{q}_F}(t) = \boldsymbol{f}\big(\theta_i(t)\big) \ \ (i = 1,2,3) \tag{2}$$

$\overrightarrow{\boldsymbol{V}_O}(t) \cdot \Delta t$ is obtained by multiplying the command velocity by the controller sampling time Δt, and represents the moving distance from the hand position to the target hand position.

In this research, gain k that can adjust the rigidity of the tip of the manipulator is used as an adjustment function to arbitrarily change the assisting force according to work situation of operators. Changing the rigidity of the tip of the manipulator means changing the overall springiness. In the case of the manipulator developed in this research, the spring constant of the whole system cannot be changed. Therefore, multiplying the moving distance $\overrightarrow{\boldsymbol{V}_O}(t) \cdot \Delta t$ from the hand position to the target hand position by the gain k, the moving distance is increased and decreased, and the resilience of the system is changed in a pseudo manner. This makes it equivalent to a change in the rigidity of the tip, making it possible to arbitrarily change the rigidity. In order to control the motor attached to the joint, it is necessary to derive each joint angle for realizing the hand position. (Eq. (3))

$$\theta_{Ti}(t+\Delta t) = f^{-1}(q_x(t+\Delta t), q_y(t+\Delta t), q_z(t+\Delta t)) \tag{3}$$

The target joint angle $\theta_{Ti}(t+\Delta t)$ is used as a command to control the position of the motor.A current is output from the position controller, which drives the motor to operate the arm.

3. Verification by actual manipulator

The designed controller is embedded on the actual manipulator control system. It is verified whether the manipulator follows the command of the operator. In the verification, it operated as a command to reciprocate in the y axis direction as a command (Fig 2).

The velocity command $\overrightarrow{\boldsymbol{V_O}}(t)$ of the operator and the tip velocity $\overrightarrow{\boldsymbol{F_F}}(t)$ of the manipulator in the verification result are shown in Fig 3.The graph in the figure is the velocity in the *x*, *y*, *z* direction from the top. In Fig 3, V_y is almost same as the velocity command. There is not so much error in other directions. Therefore, sufficient results are obtained with the proposed control method. Next, changes in the operating force and the tip velocity of the operator in the case of changing the gain k contributing to the change in the rigidity are verified. In the verification, it operated as a command to reciprocate in the *y* axis direction as a command. Gain k is compared and verified in three ways with k = 2 in (a) , k = 0.5 in (c) and with k = 1 in (b) as the reference. The *y*-axis direction velocity of each verification result is shown in Fig 4.

From Fig. 4, the maximum value of the tip velocity V_{F_y} is approximately 0.2 [m/s] in the three case, and almost the same tip velocity is achieved in the three cases. Here, for the three cases in Fig. 4, it is found that the operating force is small when the gain k

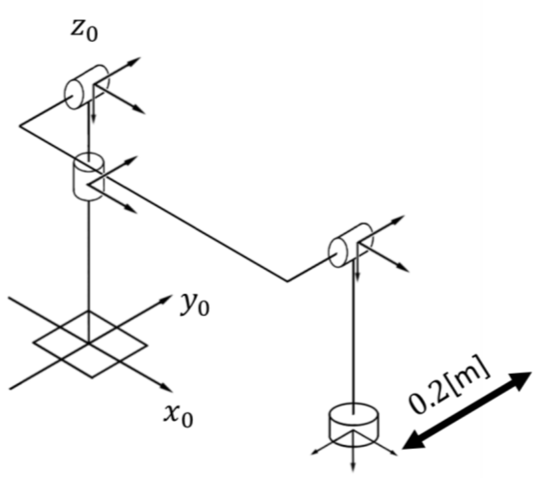
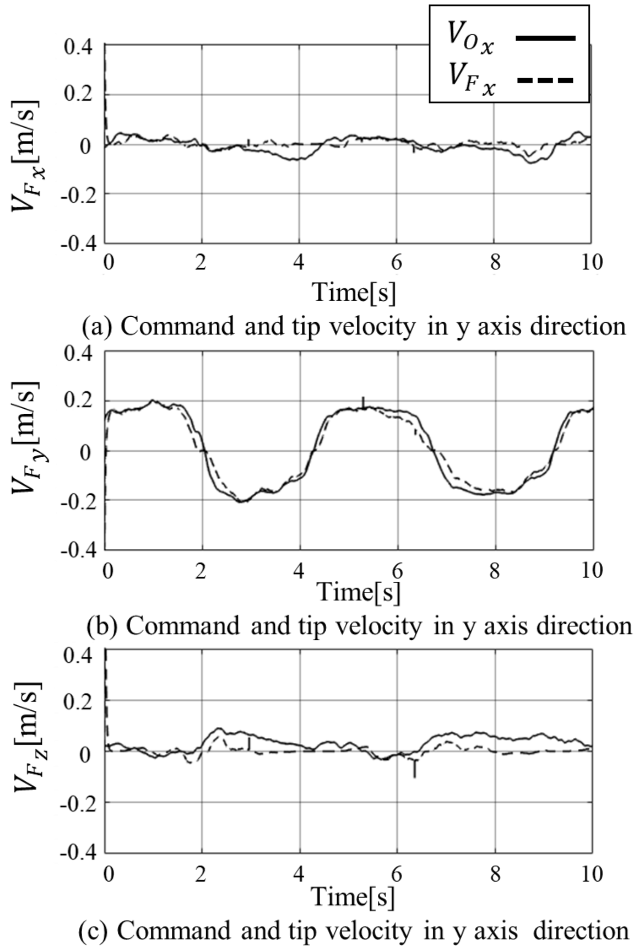


Fig. 2. Direction and size of command



(a) Command and tip velocity in y axis direction

(b) Command and tip velocity in y axis direction

(c) Command and tip velocity in y axis direction

Fig. 3. The velocity of command and robot tip

is 2 times with respect to the reference time and the operating force is large when the gain k is 0.5 times. In actual operation, when *k* is 2 times, it can operate lightly with a small force, whereas in the case of 0.5 times, it was impossible to operate without applying a large force. Therefore, it was found that the rigidity at the tip was changed.

From the above, it can be seen that the gain k that can adjust the rigidity of the tip of the manipulator functions as intended.

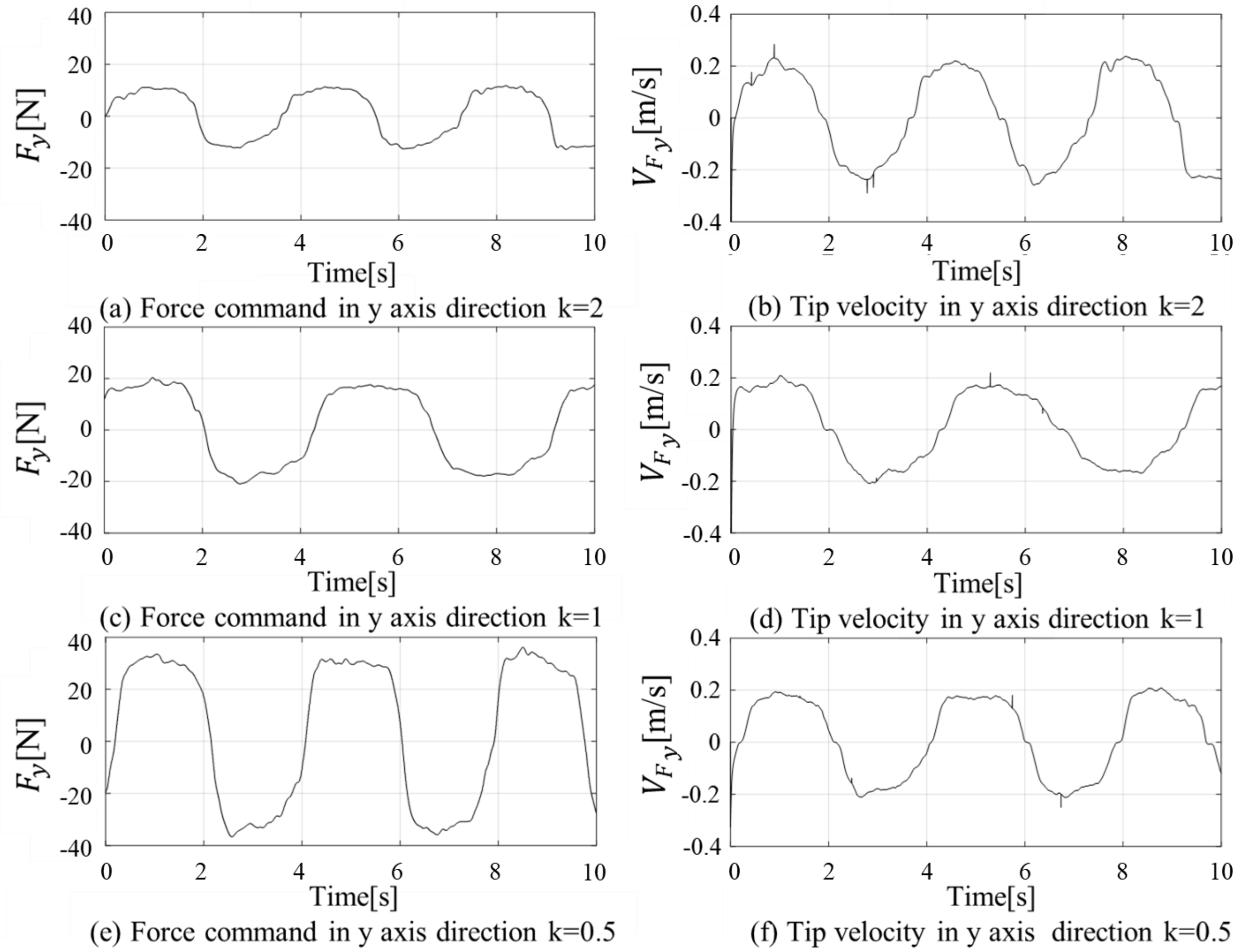


Fig. 4. Operating force and velocity of robot tip

4. Conclusion

We proposed a control to perform collaborative work by hand guide. we obtained the following.

(1) When a force is applied to the tip of the robot, it is confirmed that the operation is carried out using it as the commanded velocity.
(2) The tip velocity can be changed by manipulator tip rigidity adjustment gain, and the rigidity of the hand is able to be changed.

References

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