Co-operative Control of Plural Articulated Robot Arms by Use of Synchronous Positioning Control Technique

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Abstract

In this research, co-operative control by use of synchronous positioning control technique is proposed to realize co-operation of robot arms. The proposed method is expansion of the previous proposed contour control by using synchronous positioning control for synchronization of two links of one robot arm. Precise co-operative control of performer MK2 and performer MK3 robot arms are realized by use of the proposed method.

1. Introduction

In the industry, articulated robot arms are employed in various applications such as welding, cutting, grinding. A lot of control method have been proposed for robot arms such as time optimal control[1] and adaptive control[2]. With the advancement in industrial robotics, high-speed and precise performance are required. These requirements are difficult to realize using one robot due to the limits in speed and operating range. Then, it is suggested to employ two robot arms with co-operative control. However, co-operative control is not precise when the two robot arms are not identical. It is necessary to perfectly equalize characteristics of the motor of each axis in order to attempt the high-precise control. It is, however, very difficult to perfectly equalize characteristics.

In this research, synchronous positioning control is proposed to realize co-operative control of non-identical robot arms. The proposed method is originated by our previous proposed contour control method by using master-slave synchronous positioning based on nonlinear separation model[3], and the synchronous positioning method is used for two robots of master and slave to realize co-operative control. Precise co-operative control of performer MK2 and performer MK3 robot arms are realized by use of proposed method, even if there are different characteristics.

2. Co-operative control of plural articulated robot arms

2.1 Co-operative control

(1) Necessity of co-operative control
Co-operative control involves working of two or more robot arms complementing each other on a single task. Co-operative control is necessary when one robot arm fails to carry out the operation, due to its limits.

For example, a paste job by using one industrial robot arm, high speed operation of the robot arm is necessary to complete the process before the paste dried. When the operational speed exceeds operating limits of the robot arm, it is necessary to have another robot arm that operates in compliance so that both robot arms could be manipulated within their operating limits. Use of two robot arms increases operating speed

Fig. 1. Two link articulated robot arm

beyond what is possible with one robot arm.

(2) Approach of the co-operative control In control point of view, robot arms are independently controlled. Therefore, error for the co-operative operation occur when the robot arms are not identical without any co-operative control. Besides, when one robot is stopped by disturbance in the fixed time, it is no longer co-operative work.

In this research, synchronous positioning control is proposed to realize control of non-identical robot arms. By synchronizing the robots, it is possible to transmit position information of the master robot arm to the slave robot arm, so, that the slave robot arm can move to the position in proportion to the master robot arm. Thus, it is possible to realize co-operative control of non-identical.

2.2 Modeling of the articulated robot arm

A two-degree-of-freedom articulated robot arm is considered (see Fig.1).

l_1 and l_2 are the lengths of two links, whereas (α, β) denotes angles of two respective joints. The tip of the robot arm is positioned at (x, y) .

Inverse kinematics is used to transform working co-

ordinates to joint coordinates, as given by

$$\theta_1^i = \sin^{-1} \left(\frac{y^i}{\sqrt{(x^i)^2 + (y^i)^2}} \right) - \sin^{-1} \left(\frac{l_2^i \sin \theta_2^i}{\sqrt{(x^i)^2 + (y^i)^2}} \right) \quad (1)$$

$$\theta_2^i = \cos^{-1} \left(\frac{(x^i)^2 + (y^i)^2 - (l_1^i)^2 - (l_2^i)^2}{2l_1^i l_2^i} \right) \quad (2)$$

where i is number of robot. Kinematics is used to transform joint coordinates to working coordinates, as given by

$$x^i = l_1^i \cos \theta_1^i + l_2^i \cos(\theta_1^i + \theta_2^i) \quad (3)$$

$$y^i = l_1^i \sin \theta_1^i + l_2^i \sin(\theta_1^i + \theta_2^i) \quad (4)$$

If the dynamics of each axis is exactly expressed, higher order, above thirteenth, differential equation is required for the representation of the dynamics of the robot arms. But it has been verified that it is sufficient to use fourth order model to decide parameters that are included in the servo controller of the mechatronic servo systems. Quite often, robot arms are operated bound to 5 % of the rated speed. In such condition, joint dynamics can be approximated with the first order model[4] given by

$$\theta_{1out}^i = \frac{K_{\alpha}^i}{s + K_{\alpha}^i} \theta_{1in}^i \quad (5)$$

$$\theta_{2out}^i = \frac{K_{\beta}^i}{s + K_{\beta}^i} \theta_{2in}^i \quad (6)$$

where K_{α}^i is the position loop gain for α axis of the i th robot and K_{β}^i is that for β axis of the i th robot.

2.3 Position synchronization co-operative control

In the proposed method, the master and slave relation is used in co-operative control. It is possible to transmit position information of the master robot to the slave robot. Thereby, accuracy of co-operative control is improved. The block diagram of the proposed co-operative control is shown in Fig. 2.

$F^x(s)$ and $F^y(s)$ in Fig. 2 are the inverse dynamics of each axis of the slave robot, and f is a function from objective locus of the master robot to objective locus of the slave robot.

Function f is described in Fig. 3. It is necessary

Fig. 2. Diagram of position synchronization co-operative control

Fig. 3. Synchronize reference input function to the slave robot arm

that the slave robot be synchronized with the master robot, to realize co-operative control. Reference inputs to both robots are given using by the sampling interval, $(X_0^1, Y_0^1) \rightarrow (X_0^2, Y_0^2)$, $(X_1^1, Y_1^1) \rightarrow (X_1^2, Y_1^2)$, $\dots$,

$(X_n^1, Y_n^1) \rightarrow (X_n^2, Y_n^2)$ as shown in Fig. 3.

Thus, function f from master to slave given by

$$\begin{pmatrix} X^2 \\ Y^2 \end{pmatrix} = f \begin{pmatrix} X^1 \\ Y^1 \end{pmatrix}. \quad (7)$$

If the value calculated in equation (7) is used as the reference input to second robot arm, directly, it is not possible to synchronize two robot arms. Reason is due to the presence of the delay dynamics. Hence, in this research, the inverse dynamics is used to determine synchronized reference input to the slave robot arm by

$$X_{in}^2 = \frac{df(X_{out}^1)/dt + K_{\alpha}^2 f(X_{out}^1)}{K_{\alpha}^2} \quad (8)$$

$$Y_{in}^2 = \frac{df(Y_{out}^1)/dt + K_{\beta}^2 f(Y_{out}^1)}{K_{\beta}^2}. \quad (9)$$

3. Simulation

3.1 Conditions for simulation

In the simulation, industrial articulated robot arms of Performer MK2 and Performer MK3S (Yahatadenki-seiko) were used for co-operative control. The schematic of proposed co-operative control scheme is shown in Fig. 4. Parameter of the two robot arms are listed on Table. 1.

Fig. 4. Equipment of experiment

Table 1 Parameters of two robots for simulation study

	MK2	MK3
Length of the first link[m]	0.27	0.25
Length of the second link[m]	0.23	0.215
Position loop gain of first joint[1/s]	20	25
Position loop gain of second joint[1/s]	15	25
Encoder resolution[pulse/rev]	2000	8192
Gear ratio of first joint	160	161
Gear ratio of second joint	144	160

3.2 Simulation results

The objective locus was a straight line. MK2 was moved from one end whereas MK3S was moved from the other end. Co-operative control was carried out to improve the relative speed. The speed of MK2 was 0.05[m/s], and that of MK3S was 0.05[m/s]. Then, relative speed was 0.1[m/s]. This result is shown in Fig. 5.

As shown in Fig. 5, the X-Y locus of the two robots are on the line and the co-operative operation is realized.

The next simulation was for disturbance contaminated case. The disturbance was applied such that Performer MK2 was stopped from 0.2[s] to 0.3[s]. The simulation result is shown in Fig. 6. As shown in Fig. 6, the co-operation control can be realized even if the disturbance is contaminated.

Of cause, the proposed co-operative control is effective for the disturbance of master robot and is not effective for that of slave robot.

4. Conclusion

In this paper, co-operative control was realized based on position synchronization in that the slave robot follows the motion of the master robot. By this way it is also possible to raise the operating speed. The proposed method could be used to synchronize many robot arms on co-operative control.

References

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Fig. 5. Simulation result without disturbance

Fig. 6. Simulation result with disturbance

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