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Dual Mode Control for the Robot with Redundant Degree of Freedom

- The application of the preview learning control to the gross motion part -

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ABSTRACT: This paper deals with a dual mode control system design for the starching work robot. From the feature of this work, the robot has redundant degree of freedom. In this paper, we try to split the whole movemen' ᶠ the robot into a gross motion part aı ˴ a fine motion part so as to achieve a good tracking performance. The preview learning control is applied to the gross motion part. The validity of the dual mode control architecture is demonstrated.

I. INTRODUCTION

Representative methods to use the redundant degree of freedom of the robots are concerned with avoiding obstacles or keeping a posture of the arm (Hanafusa, H., T. Yoshikawa and Y. Nakamura, 1983; Nakamura, Y. and H. Hanafusa, 1985). In addition to these, there exists an idea that the whole movement of the robot should be split into a gross motion part and a fine motion part so as to achieve a good tracking performance (Kuntze, H. -B., 1990). The gross motion part can move widely but slowly and roughly, on the contrary, the fine motion part can move sharply and finely but its movement range is narrow, and the control system is designed precisely based on their characters.

In conformity with this concept, a design method using the H∞ control has been proposed (Sampei, M., H. Itoh and T. Mita, 1991). In this paper, we apply the preview learning control to the gross motion part.

II. CONTROLLED OBJECT AND PROBLEM FORMULATION

We study the control design problem for starching work. The features of this work are arranged as follows.

a) A trajectory of a starching line in three-dimensional space is given beforehand. It is not a function of time.

b) A movement speed of the fingertip must be constant, because paste is fed constantly.

c) A posture of the finger (nozzle) is not required to be vertical to the work surface strictly. Therefore, in the case of using multi-joint arm robots which have some degrees of freedom, we have redundant degree of freedom.

It is assumed that there is no obstacle in a working area, therefore this redundant degree of freedom can be used only for getting a good tracking performance.

For simplicity, we consider the following controlled object model.

$$Y(s)=Gg(s)Ug(s)+Gf(s)Uf(s) \qquad (1)$$

$$Gg(s)=\frac{kg\omega g^2}{s^2+2\zeta g\omega g s+\omega g^2} \qquad (2)$$

$$Gf(s)=\frac{kf\omega f^2}{s^2+2\zeta f\omega f s+\omega f^2} \qquad (3)$$

$$kg=10,\quad \omega g=2\pi,\quad \zeta g=0.8,$$
$$kf=10,\quad \omega f=50\pi,\quad \zeta f=0.4$$

where, Gg(s) and Gf(s) denote transfer functions of the gross motion part and the fine motion part respectively, and it is

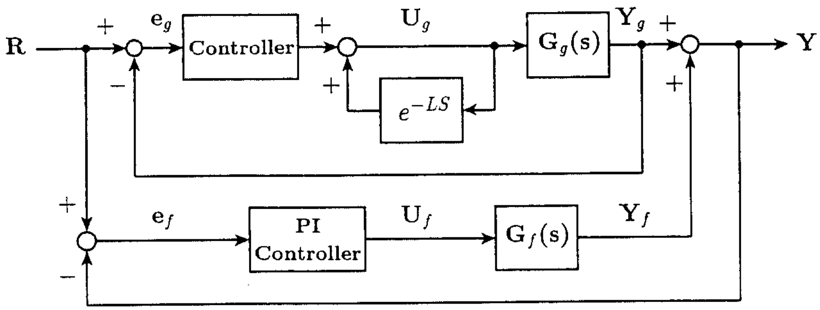


Fig.1 Structure of dual mode control system

assumed that there is no interactive force between the two parts.

From the feature of the starching work, we apply the preview learning control (Nakamura, H., 1991) to the gross motion part.

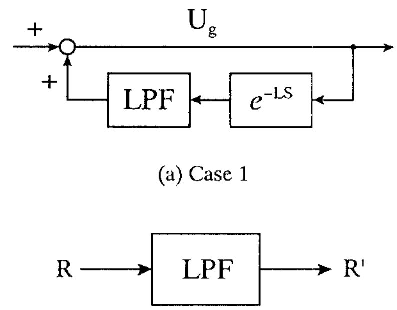
III, CONTROL SYSTEM DESIGN

A structure of a dual mode control system is shown in Fig. 1. The gross motion part will track the reference value by itself without considering a movement of the fine motion part, on the contrary, the fine motion part should compensate tracking errors positively, which will be remained by the gross motion part. The fine motion part is controlled by the PI control.

If the controlled object transfer function is strictly proper and the reference line is angular, it is known that the learning control system will be unstable (Nakano, M., T. Inoue, Y. Yamamoto and S. Hara, 1989). In order to guarantee the stability of this learning control system, a low pass filter is usually used. Fig. 2 shows locations of inserting the low pass filter. We will examine the dual mode control system in two cases.

IV. PREVIEW LEARNING CONTROL

The preview learning control, proposed by Nakamura, H. (1991), has merits of both the preview control and the learning control. The preview learning control achieves the high accurate tracking which is the feature of the learning scheme, and it is able to cope with the hasty change of the reference value by the preview



(a) Case 1

(b) Case 2

Fig.2 Locations of low pass filter

scheme. In addition, the convergence speed of the learning is very fast.

The algorithm of the preview learning control is arranged as follows.

$$u_k(i) = u_{k-1}(i) + \sigma_k(i) \tag{4}$$

$$\sigma_k(i) = \sigma_k(i+1) + \Delta\sigma_k(i) \tag{5}$$

$$\Delta\sigma_k(i) = \sum_{m=1}^{M} q_m \, e_{k-1}(i+m) + Q\{e_k(i) - e_{k-1}(i)\} - \sum_{n=1}^{N-1} g_n \, \Delta\sigma_k(i-n) \tag{6}$$

$$q_m = W_m H_m / \{\sum_{j=1}^{M} W_i H_j^2\}, \quad m=1,2,\ldots,M \tag{7}$$

$$Q = \sum_{m=1}^{M} q_m \tag{8}$$

$$g_n = \sum_{m=1}^{M} q_m (H_{n+m} - H_n), \quad n=1,2,\ldots,N-1 \tag{9}$$

where, H_n, $n=1, 2, \ldots, N-1$ denote the sampled values of the gross motion part step response, N is the sampling number

when the step response settles adequately, and M means a preview step number.
$\sigma k(i)$ is a revised amount for the control variable uk-1(i), where, k denotes a number of repetition and i denotes time (t=iT, T is a sampling period). $\Delta\sigma k(i)$, which can be calculated from eqns. (6)-(9), has been determined in order to minimize the following criterion which consists of forecasted control errors $e^*k(i+1)$, $e^*k(i+2)$, ..., $e^*k(i+M)$.

$$J = \sum_{j=1}^{M} Wm \{e^*k(i+m)\}^2 \qquad (10)$$

where, Wm is a suitable weighting function of m.

V. TWO-DIMENSIONAL TRAJECTORY TRACKING

Let us try to check the tracking performance of the preview learning dual mode control in two-dimensional space. Fig. 3 shows a given starching line which is a model of a side-window of a car. In this simulation test, we use the following values.

Sampling period
gross motion control : 0.05 [s]
fine motion control : 0.01 [s]
Speed of nozzle : 1 [m/s]
Settling step number N=20 [steps]
Preview step number M=14 [steps]
Weighting function
$Wm = \exp\{-(m-1)/2\}$
Break frequency of
low pass filter : 7 [Hz]

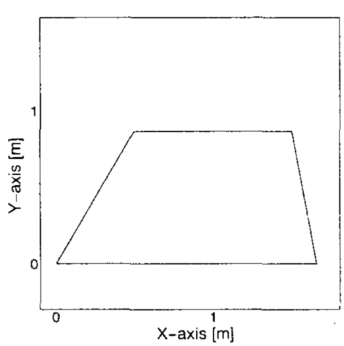


Fig.3 Reference trajectory of starching line in two-dimensional space

And, the PI controller parameters Kp and Ki are tuned at the values 0.025 and 0.007 respectively.

As the movement speed of the starching nozzle is required at 1 [m/s], the two-dimensional trajectory of starching line shown in Fig. 3 is transformed to a function of time for the x-axis as shown in Fig. 4. One cycle needs about 4.54 [s].

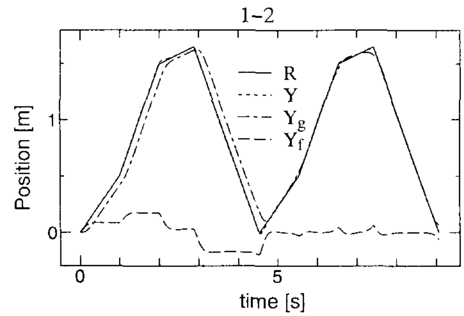
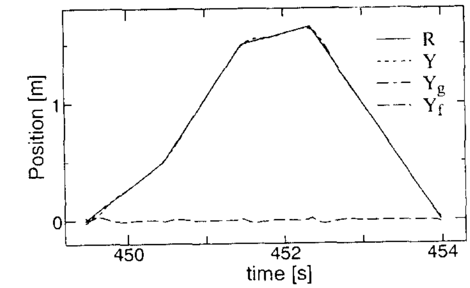


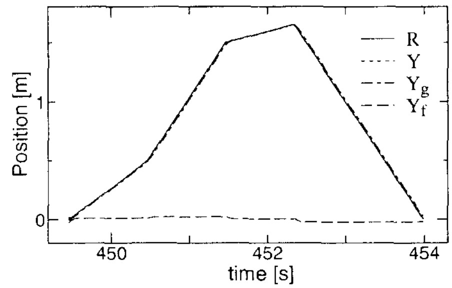
Fig.4 Reference trajectory and process of learning (x-axis)

Fig. 4 also shows a process of the learning. In the first repetition, the gross motion part output Yg cannot track the starching line and the fine motion part output Yf moves widely to cover the control error. We can see that Yg tracks the starching line pretty well in the second repetition but it cannot follow the quick change because of its long rising time.

After one hundred repetitions, the gross motion part control error became too small as shown in Fig. 5. Case 1 means that the low pass filter is set in the feedback line of lag, and Case 2 means that the low pass filter is set as a reference filter for the gross motion part (See Fig. 2).
Fig. 6 shows the control errors, eg is the gross motion part error which corresponds to a distance among the reference value and the wrist, and ef is a distance among the reference value and the fingertip. In the Case 2, there exists a steady state error for the gross motion part, but the fine motion part compensates well. Fig. 7 shows the time responses of the control variables. Mixing the x-axis and the Y-axis, the tracking performance represented in two-dimensional space becomes as shown in Fig. 8.

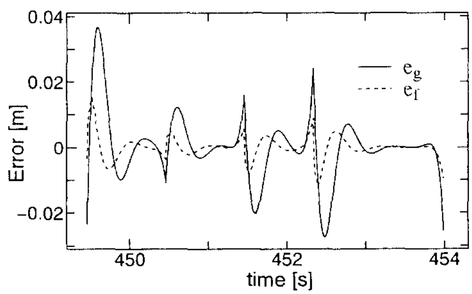


(a) Case 1

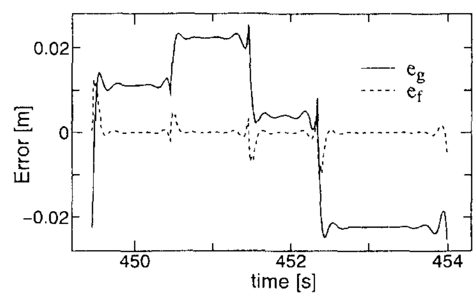


(b) Case 2

Fig.5 Tracking trajectory (x-axis)

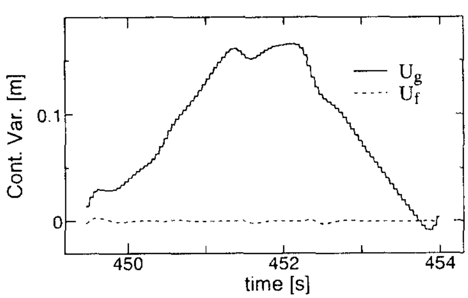


(a) Case 1

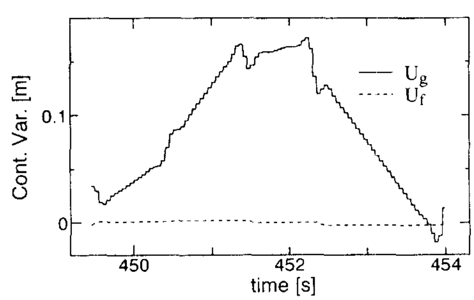


(b) Case 2

Fig.6 Time responses of control errors (x-axis)

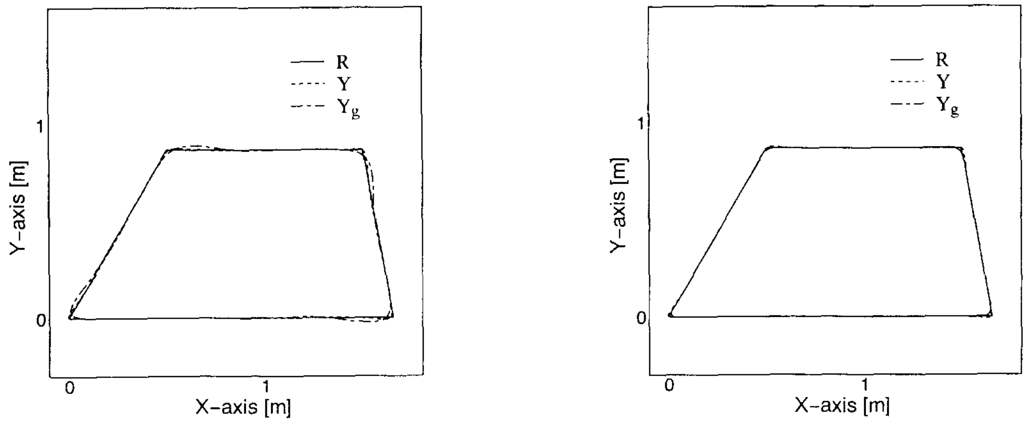


(a) Case 1



(b) Case 2

Fig.7 Time responses of control variables (x-axis)



(a) Case 1 (b) Case 2

Fig.8 Tracking performance

VI. CONCLUSION

We have studied the control design problem for starching work. A preview learning dual mode controller has been proposed. When a robot has redundant degree of freedom, it is useful to split the whole movement of the robot into the gross motion part and the fine motion part. Based on their characters, we have designed control systems. We applied the preview learning control to the gross motion part, and for the fine motion part we used PI control.

REFERENCES

Hanafusa, H., T. Yoshikawa and Y. Nakamura (1983) : Redundancy analysis of articulated robot and its utilization for tasks with priority, Trans. Soc.Instrum. Control Engrs, in Japanese, 19-5, 421/426

Kuntze, H. -B. (1990) : Integrated mechatronics design of robots, Proc. CEC Workshop on computer integrated design of controlled industrial systems, Brussels

Nakamura, H. (1991) : Preview learning control and its application to position control of servomotors, Trans.Soc.Instrum. Control Engrs, in Japanese, 27-12, 1382/1388

Nakamura, Y. and H. Hanafusa (1985) : Optimal redundancy control of articulated robot arms, Trans. Soc. Instrum. Control Engrs, in Japanese, 21-5, 501/507

Nakano, M., T. Inoue, Y. Yamamoto and S. Hara (1989) : Repetitive control, Soc. Instrum. Control Engrs, in Japanese

Sampei, M., H. Itoh and T. Mita (1991) : H∞ control of a plant with redundant degree of freedom, 20th SICE Symposium on Control Theory, in Japanese, 101/104