메카트로닉스 서보시스템의 고속 고정밀 운전을 위한 궤적 데이터 생성법

論 文
53D-1-7

Trajectory Data Generating Method for Higher Speed and Higher Accurate of Mechatronics Servo Systems

鄭 大 源*
(Dae Won CHUNG)

Abstract – Reference trajectory generation plays a key role in the computer control for accurate position control of machine. Generated trajectories must not only describe the desired tool path accurately, but must also have smooth kinetic profiles in order to maintain higher tracking accuracy, and to avoid exciting the natural modes of the mechanical servo control system. To achieve higher accurate position control, a method of limiting accelerating and decelerating speed data of reference trajectories is proposed to draw the path with an assigned accuracy without any complex operations.

Key Words : mechanical servo control system, referenced input trajectory, position control, speed data

1. INTRODUCTION

For the machine action of mechanical servo systems such as industrial robot arms and NC machines, the objective referenced trajectory data have been directly used as the input data. In the most cases for higher accurate position tracking, the motion could be realized usually to maintain as the minimum level of speed. But a required speed of servo system movement much depends on the design purpose of servo system motions. Generally speaking, the higher the speed of machine operation is required, the less accurate the control performance is obtained. This means that it is very difficult to achieve both the most accurate and the highest speed control of servo systems. However, in case of existing modeling errors, the control performance is deteriorated and a slight overshoot of the trajectory is also observed. This kind of overshoot should be avoided for the desirable performance in the industrial robot arms.

In this paper we proposed a new method by limiting the accelerating and decelerating speed data of objective referenced trajectory input data to improve the properties(accuracy and speed) of position control of the mechanical servo systems. The currently available methods are usually capable of making suitable speed data so as to satisfy a given accuracy of position control. This method conquers the overshoot problems even if there are some modeling errors in a given system.

* 正 會 員 : 湖南大學校 電氣工學科 副敎授, 工博
接受日字 : 2003년 5월 23일
最終完了 : 2003년 11월 5일

2. BASIC PRINCIPLE AND METHOD

2.1.BASIC PRINCIPLE

The successive straight lines usually approximate the objective trajectory path of mechanical servo system. The position moves the trajectory following the input command of position and speed. The basic idea is to limit only acceleration and deceleration of the speed data from the desired speed to improve accuracy of position control. To obtain the accurate position, the actual speed around the corners of the approximated reference path must be slow. We should have to limit the accelerating and decelerating the speed data of given trajectory as slowly as possible while maintaining the position data at the desired trajectory. For this requirement, we proposed to limit the accelerating and decelerating speed at the near corner of reference tracking paths.

2.2 PROPOSED METHOD

Let's think about a straight lined path length L which is one of the approximated objective lines. The mechanical servo system may be represented as the independent one input and output system of each approximated objective line. We describe the mechanical servo system by a second order model with the simple approximated model in Fig. 1[1,2].

From Fig. 1, we may obtain the input and out transfer function of Laplace transformation in the equation (1).

$$Y(s)=\frac{K_pK_v}{s^2+K_vs+K_pK_v}R(s) \tag{1}$$

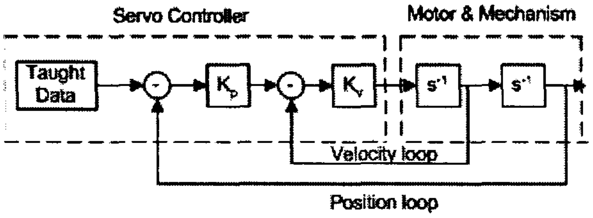

Fig. 1 The second ordered simple model of a servo system

where, R(s) is objective referenced input data, Y(s) is output of the given system, K_p , K_v are the position loop gain and the velocity loop gain, respectively. To achieve the accurate position control of machine, we should have to limit the accelerating and decelerating the speed data of given trajectory as slowly as possible while maintaining the position data at the desired trajectory. This is basic principle to achieve high accuracy while maintaining the high speed as fast as possible. Then, the speed will be reduced from the desired speed V_d to minimum speed V_{min}. Therefore, the speed of given machine is described at the corner of reference path as;

$$v(t) = \frac{dr(t)}{dt} = V_d - at \tag{2}$$

where, $a = \frac{V_d - V_{min}}{T_a}$

$$r(t) = \int_0 v(\tau)d\tau = V_d t - \frac{1}{2}at^2 \tag{3}$$

We may obtain the input trajectory of equation (3) from equation (2). If we put $r(0)=0$ for simplicity of determining T_a and by the substituting the Laplace transform of equation (3) into equation (1), the actual traveled distance $y(t)$ is obtained by the inverse Laplace transformation as equation (4);

$$y(t) \approx -\frac{1}{2}at^2 + \left(V_d + \frac{a}{K_p}\right)t + \frac{1}{K_pK_v} - \frac{a}{K_p^2} - \frac{V_d}{K_p} \tag{4}$$

where, transient terms are small and neglected under the assumption of $T_a \rangle \frac{3\tau}{2}$,

where, $\tau = \frac{2}{K_v - \sqrt{K_v^2 - 4K_pK_v}}$ means the maximum time constant of given machine.

Our objective is that the position of the given machine reaches the assigned point at time T_a with desired accuracy. Then, actual moving position of machine will be as follows;

$$y(T_a) = r(T_a) - R \tag{5}$$

where R is the allowable position deviation between the actual position and the objective referenced position at the time T_a. By substituting (3) and (4) into (5) and solving for T_a, we may obtain the following equation (6).

$$T_a = \frac{(K_v - K_p)(V_d - V_{min})}{K_pK_v(K_pR - V_{min})} \tag{6}$$

By decelerating the speed during the time interval T_a, we may be able to maintain the desired accuracy of the position of machine.

Next, we derive the speed around the starting point of the strait line L. In order to maintain the required accuracy at the corner of the approximated objective path, the speed up to time $T_a = 3\tau$ is assigned at the minimum speed V_{min}. Then, the machine is accelerated from the minimum speed V_{min} to the desired speed V_d during time interval T_a. When the speed is accelerated to the desired speed V_d, the speed may be fixed at the desired speed V_d during the time interval T_v. The time T_v is calculated from the fact that the integral of the speed equals to the moved length of line L as follows;

$$T_v = \frac{L - 3V_{min}\tau - (V_d + V_{min})T_a}{V_d} \tag{7}$$

As a result, we may obtain the required speed data at each stage of movement as follows;

$$v(t) = \begin{cases} V_{min} \\ V_{min} + a(t - 3\tau) \\ V_d \\ V_d - a(t - 3\tau - T_a - T_v) \end{cases} \tag{8}$$

These may be illustrated the desired input speed of time chart in the Fig. 2, 3 and 4.

2.3.PARAMETER SELECTION CRITERIA

In order to determine T_a in equation (6), we must select the parameters V_d, V_{min} and R. The desired speed V_d depends on the purpose of servo systems. We select the minimum speed V_{min} by the objects and/or the trade off between efficiency and accuracy of machine.

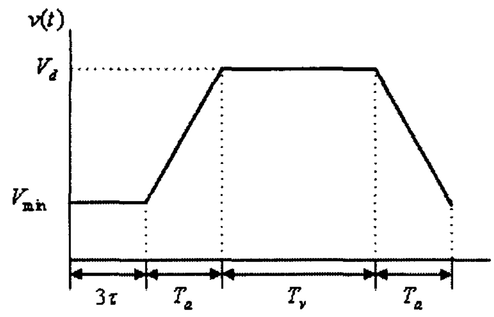

Fig. 2 Input speed data for the straight lined path

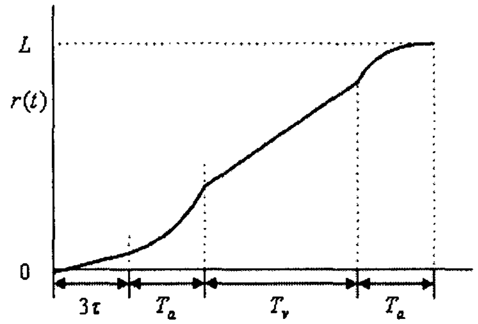

Fig. 3 Reference position trajectory data of a line

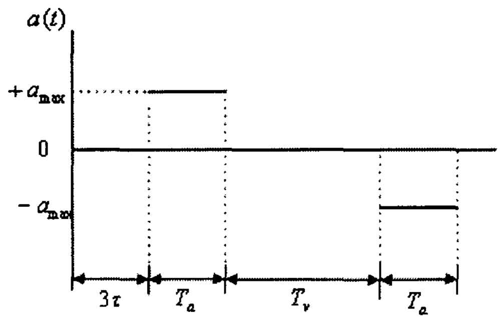

Fig. 4 Maximum acceleration and deceleration data

The position deviation parameter R is selected by considering the objective of position control and some restrictions. The first restriction is that the acceleration of the point of corners must be less than the maximum acceleration of the servo motor of mechanical actuator, which is described by;

$$\frac{V_{\min}^2}{R} \le a_{\max} \tag{9}$$

where $a_{\max}$ is the maximum acceleration of the servo motor. The second restriction is that R must be bigger than the steady-state velocity error at the speed $V_{\min}$ of $\frac{V_{\min}}{K_p}$,

i.e.,

$$R \ge \frac{V_{\min}}{K_p} \tag{10}$$

As a result, the position deviation parameter R must be selected so as to satisfy the restrictions of (9) and (10) as follows;

$$\max\left\{\frac{V_{\min}}{K_p}, \frac{V_{\min}^2}{a_{max}}\right\} \le R \tag{11}$$

3. PERFORMANCE EVALUATION

3.1. COMPUTER SIMULATION

In order to evaluate the performance of proposed method, computer simulation has been done under the conditions and operating data in Table 1.

Table 1. Selection parameters for simulation

symbol	Description	Value	Units
K_v	Velocity gain	58	1/sec
L	Travel distance	4	cm
V_d	Desired speed	4	cm/sec
$V_{\min}$	Minimum speed	1	cm/sec
$a_{\max}$	Maximum acceleration	42.2	cm/sec^2
R	Deviation parameter	0.2	cm

To assure the effectiveness of the proposed method in speed and accuracy, we compared the proposed method with conventional method. The conventional method is that the inputs of path and speed data are the same as the objective one. Another method is that the path input is the same as the objective path and the speed is assigned as the minimum speed $V_{\min}$.

3.2 EVALUATION

At first, we evaluate the accuracy by comparing the deviation of the following trajectory from the objective trajectory at the ending point of line L. The deviation of proposed method is assigned by the deviation parameter R. The deviations of other methods are calculated from the steady-state velocity error of the system (1) at the speed as $\frac{V_d}{K_p}$ and $\frac{V_{\min}}{K_p}$, respectively. In the computer simulation, the deviation parameter is obtained as 0.2 [cm] for the proposed method, 0.4[cm]for conventional method, 0.1[cm] for minimum speed method, respectively. The proposed method is much smaller than the conventional method. And the minimum speed method is the smallest accurate following path but the speed is slowest as we see in the Fig. 5,6,7 and 8.

Next, we evaluate the operating time of three methods. The total operating time of the proposed method is $T_t = T_v + 2T_a + 3\tau$, whereas the time of other methods are obtained from division of the distance as $\frac{L}{V_d}$ and $\frac{L}{V_{min}}$, respectively. The time of proposed method is almost same as the time of conventional method when the distance of the objective line is long enough. The operating time in computer simulation is obtained 1.37sec for proposed method, 1.0 sec for conventional method, and 4.0 sec for minimum speed method.

As a result, the proposed method is better than conventional and minimum speed method on the points of view of high accuracy and higher speed. The other advantage of the proposed method is the ability to adjust the desired speed of servo system appropriately to get the desired speed and accuracy.

We further discuss the robustness of the proposed method. The servo system (1) is assumed to be adjustable to have no overshoot in the following trajectory. If some modeling errors exist, the taught speed is different from the optimal taught speed because the parameters, τ, T_a, T_v, a in equation (8) is different from the optimal parameters. However, the proposed method has no overshoot even if the modeling errors exist under assumption of the taught position is the same as the original one.

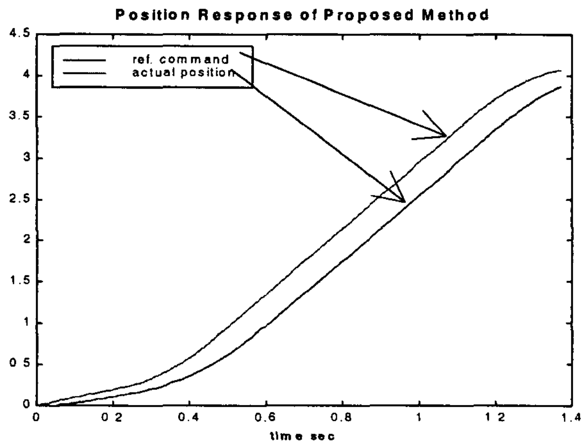

Fig. 5 Position Tracking Response of Proposed Method

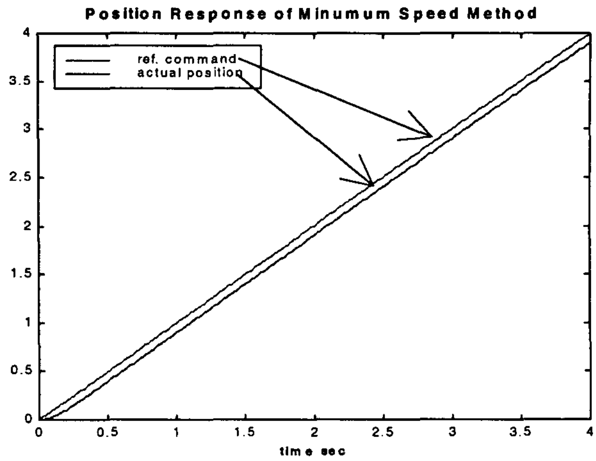

Fig. 6 Position Tracking Response of Minimum Speed Method

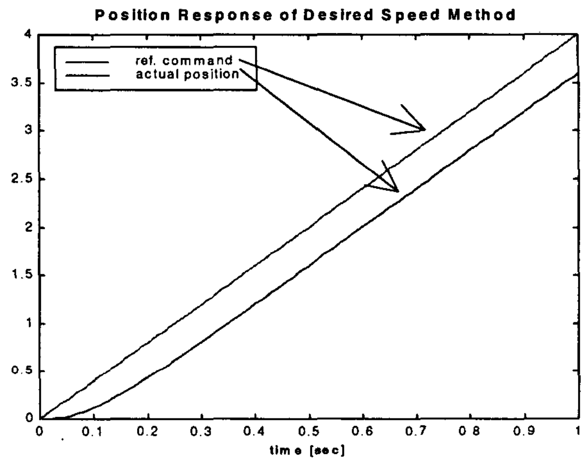

Fig. 7 Position Response of Desired Speed Method

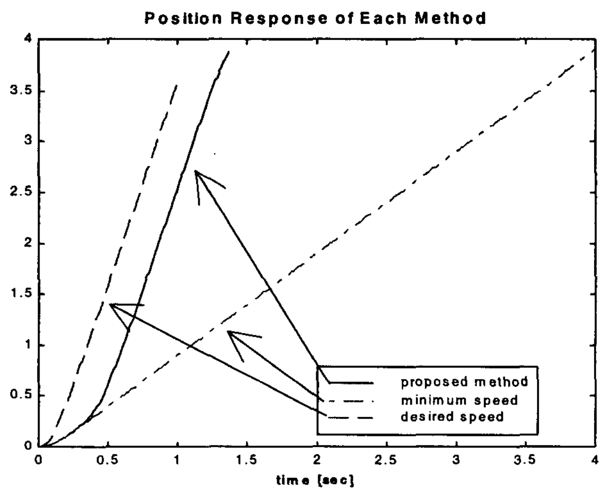

Fig. 8 Position Response Comparison For Each Method

4. Conclusion

We propose a method of limiting acceleration of speed data on speed information. It has the characteristics of higher accuracy and higher speed of mechanical servo system than any other available methods. The method is to modify the speed data to achieve an accurate trajectory close to the objective one. The simulation result shows the usefulness of the proposed method, which can be effectively and easily applied to position control problems without any changes of the hardware in general mechanical servo systems.

5. References

[1] N. Kyura, *Practical Mechantronics Motion Control*, Industrial Publishing Co., 1996.
[2] S. Goto. M. Nakamura and N. Kyura, *"Method for Modifying Taught Data for Accurate High Speed Positioning of Robot Arm"* SICE Trans. 27-12, pp 1396-1404, 1991, in Japan.
[3] H. Nakamura, "Preview-Learning Control and its Application to Position Control of Servomotors," SICE Trans., 27-12, pp 1382-1388, 1991 in Japan.
[4] 정대원, 양승학, *Motion Control*, 대영사, 2003.

저 자 소 개

정 대 원(鄭 大 源)

He was born in 1957. He received B.S. degree from Pusan University, Korea in 1983, M.S. and Ph.D. degrees in electrical engineering from Chungnam University, Korea in 1996 and 2000, respectively. From 1982 to 1996, he has been a senior researcher of Korea Atomic Energy Research Institute. Since 1997, he has been a Professor at Department of Electrical Engineering, Honam University. His research interests are in the area of mechatronics servo systems, power system control, advanced and intelligent control techniques and embedded systems, etc. E-mail : dwchung@honam.ac.kr