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Precise Digital Tracking Controller for CNC Machine Tools

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Abstract - The purpose of this paper is a fuzzy logic controller for XY positioning system. The overall control system consists of three parts, the position controller, the speed controller, the fuzzy logic controller. Precise tracking is achieved by fuzzy logic controller. In practice, such systems contain many uncertainties. Therefore, the XY positioning system must receive and evaluate the motion of all axis for a better contouring accuracy. Cross coupled controller utilizes all axis position error information simultaneously to produce accurate contours. However, the existing Cross coupled controllers cannot overcome friction, backlash and parameter variation. So, we propose a fuzzy logic controller of XY positioning system. Experimental results show that the proposed fuzzy logic controller is effective to improve the contouring accuracy of XY positioning system.

1. INTRODUCTION

In modern industrial field, automation has been pursued for many years. For example, positioning systems or multi-axial robots are equipped in manufacturing plants. When the positioning systems are tracked by specified trajectories, the trajectories are decomposed by the movement of each axis actuators. When multi-dimensional movement is controlled, the error is occurred by each axis actuator, which causes whole tracking error or contour error. Fundamentally, if the plant input cannot tracked well, the tracking error is main factor which occurs contour errors. Therefore, at first, reducing the tracking error contributes to the total performance improvement. Most controllers are designed under the assumption which is the optimal condition. Using this assumption, the chosen controller is applied to the real system. In this way, sometimes desired output cannot obtained because of disturbances or modeling errors[1][2].

Especially, these errors occur big damages to the system performance in the field which require very accurate control. For these reasons it is important to develop a control algorithm that can account for the nonlinearities and at the same time to be robust to uncertainties such as inertia load and friction characteristics. For achieving this purpose, of use the Fuzzy Logic Controller affect robustness in the disturbances and the uncertainties[5][6]. If this phenomenon is not considered and each axis is controlled independently, the contour error is occurred. As a result, it depreciates the system performance. Therefore, reducing the contour error is more necessary than reducing the tracking error in the positioning system. So, many investigators have developed techniques for reducing contour error in multi- axis positioning system. So, the dynamics mismatch is one of main causes of contour error under typical matching conditions. Hence to reduce calculated contour error, the input of a Cross Coupled Controller[2][3][4] is used. However, the existing cross coupled controllers cannot overcome friction, backlash and parameter variation. Therefore, in this paper, a Fuzzy Logic Controller(FLC) is proposed to improve the accuracy of the XY positioning system. And also, comparison of the control performance between conventional PD and the proposed FLC. Cross Coupled Control is equipped simultaneously.

2. TRACKING AND CONTOUR ERROR

2.1 Tracking error

The tracking error is defined to be the difference between the desired location and actual location. In real physical field, inertia, friction and other nonlinear factors are mixed and there also exist time delay. So, if reference input is time varying, that is not constant, than output is not fellow the reference input and there occurs tracking error[2].

2.2 Contour error

The contour error is defined to be the difference between the desired path and actual path. It is shown in Fig. 1. And it is calculated by equation(4). Generally, contour error is the function of inclination(θ), which is the function between each axis position error and reference trajectory.[2]

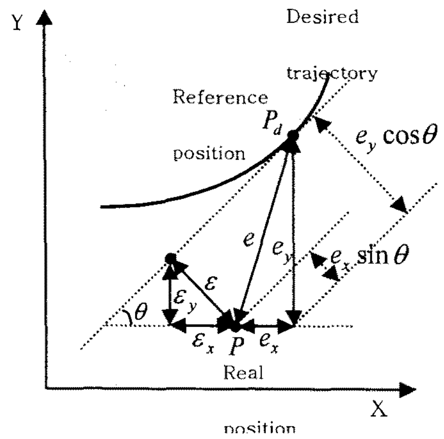

Fig.1 Definition of tracking and contour error

$$\varepsilon(t) = e_y(t)\cos\theta - e_x(t)\sin\theta \qquad (2)$$

where, $e_x(t)$ and $e_y(t)$ are the position errors along the individual axes. θ is the inclination of the contour with respect to the x-axis and ε is the contour error.

$$\theta = \arctan\left(\frac{v_y}{v_x}\right) \qquad (3)$$

where, v_x and v_y are velocity factors of x and y axes in reference trajectory.

3. Cross-coupled controller (CCC)

When one axis load or disturbance is sudden changed, to correct this phenomenon, that is, reduces contour error not only the one axis but also another axis is compensated simultaneously. To control the motion of resolved each axis, we equipped the controller every axis. When we control multi-axis system using cross-coupled controller, we can give compensation input which calculated with contour error, and can reduce the contour error [3].

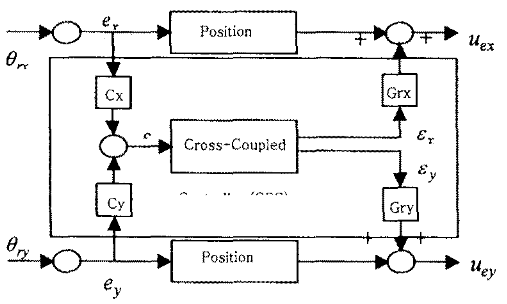

Fig.2 Cross Coupled Controller

It is fundamental expression. that equation (4) which generate control input by position error and contour error.

$$u_x = K_{px}e_x + G_{px}\varepsilon_x$$
$$u_y = K_{py}e_y + G_{py}\varepsilon_y \qquad (4)$$

where, *Kpx* and *Kpy* are feedback controller, *Gpx* and *Gpy* are cross-coupled controller, *ex* and *ey* are tracking error component, and ε_x and ε_y are contour error component.

The components of the contour error are determined as

$$\varepsilon_x = -m_y\varepsilon = m_y^2 e_x - m_x m_y e_y$$
$$\varepsilon_y = -m_x\varepsilon = m_x^2 e_y - m_x m_y e_x \qquad (5)$$

where, $m_x = \sin\theta$, $m_y = \cos\theta$

3.1 Formulation of Fuzzy Logic Controlle

A typical fuzzy rule based controller can be represented as Fig.3. The fuzzy controller inputs are e_k and Δe_k ,and the output is u_k.e_k denotes a control error, i.e., difference between a reference input and an actual process output at time step k [5][6]. de_k is a change in control error between time step $k-1$ and k ,i.e.,

$$\Delta e_k = e_k - e_{k-1} \qquad (6)$$

We have defined seven fuzzy sets for each controller input and for the controller output, respectively. Two kinds of shapes are used for the membership functions: one is a triangle, and the other is a trapezoid which corresponds to both ends of the fuzzy input and output ranges.

4. CORSS COUPLED FUZZY LOGIC CONTROLLER

Here, since there are two fuzzy controller inputs and one output and the number of fuzzy sets for each controller input is seven, there are 49 control rules stored in the rule base, and the control rules can be represented by :

$$\text{Rule } R_{ij}: E = A_i \ \ \Delta E = B_j \text{ and IF}$$
$$THEN \ \ U = C_{ij}, \quad i,j = 1,\ldots,7 \qquad (7)$$

Through fuzzy reasoning with the fuzzy control rule base, the fuzzified inputs E and ΔE can be transformed into an output U. We used Mamdanis maximum-minimum operation method i.e., if we have the above form of control rules[7], the overall truth value of resulting inference C at time step k can be obtained by

$$\mu_C(u_k) = \max_{i,j}[\min(w_{ij}, \mu_{Cij}(u_k))] \qquad (8)$$

where, $w_{ij} = \min(\mu_{Ai}(e_k), \mu_{Bj}(\Delta e_k))$

Since the output U is the truth x also has fuzzy values, a defuzzification procedure is needed to obtain a crisp value output. There are several defuzzification methods, and the center of gravity method shown below is used.

$$u_k = \frac{\sum_{i=1}^{n} \mu(u(i)) \bullet u(i)}{\sum_{i=1}^{n} \mu(u(i))} \qquad (9)$$

where, $\mu(u(i))$is a truth value when u has a quantized value $u(i)$, and n is the number of discretized levels in the output range. Proposed whole system structure is below. The radial tracking error is defined as

$$e_t = \sqrt{(x_r - x_p)^2 + (y_r - y_p)^2} \tag{10}$$

and the radial contour error is defined as

$$e_c = \sqrt{(x_p - r)^2 + (y_p - r)^2} \tag{11}$$

where , x_r and y_r are desired position, x_p and y_p are actual position and r is the radius.

5. EXPERIMENTAL RESULTS

To validate the proposed control strategy, a XY positioning is implemented. XY positioning system has 500 mm by 500 mm area. Each axis is driven by a ball-lead screw (10 mm/revolution) which is connected to a actuator system ,100 and 200 watts AC servo motor in each axis respectively. Linear position encoders are mounted on each axis. The resolution of the linear encoders is 5 micron meter. The servo controller is realized by a 32-bit microprocessor, the TMS 320c31. The microprocessor is equipped with a 32-bit floating point mathematical computation operation.

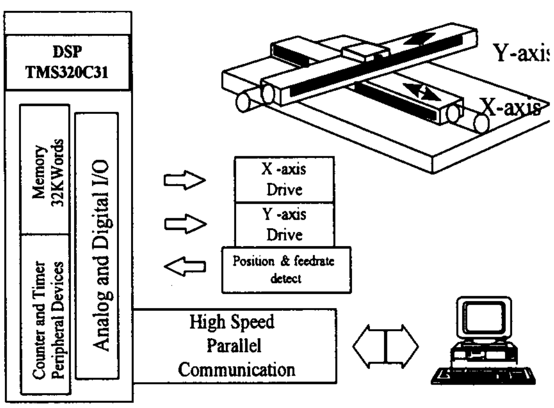

Fig. 3 Block diagram of the positioning control system

The term contour error is used to denote the error component that is orthogonal to the desired contour. The performance of Fuzzy Logic Controller (FLC) has been examined through experiments under the various uncertainties and external disturbances. So, comprison of the control performance between conventional PD and the proposed FLC. Cross Coupled Control is quipped simultaneously. Also, we performed the PD and FLC for a circular contour of 10 [mm] radius, and compared the results in figures. Fig. 4, 5 and 6 shown that experimental results. As can be seen, we performed the FLC and the PD control for a circular contour of 10[mm] and compared the results in Fig.4. As shown Fig.5 and 6, for the low feedrate, the FLC considerably reduced the large error which occurs at every quarter circle. Similarly, for the higher feedrate, the contour error were also reduced. By comparing the experimental results obtained from FLC, it can be seen that the performance of the FLC is better than that of the PD control.

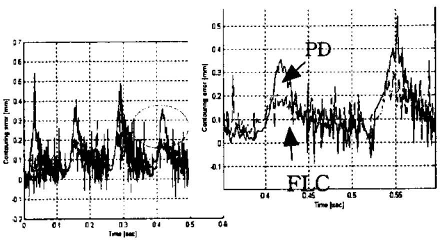

Fig.4 Experimental results
Conditions: PDCCC .vs. FLCCC

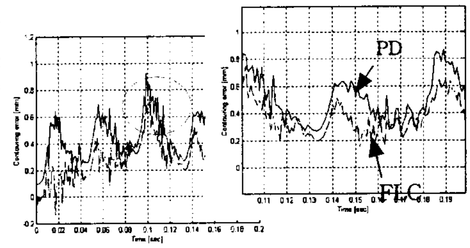

Fig.5 Experimental results
Conditions: feedrate * 3

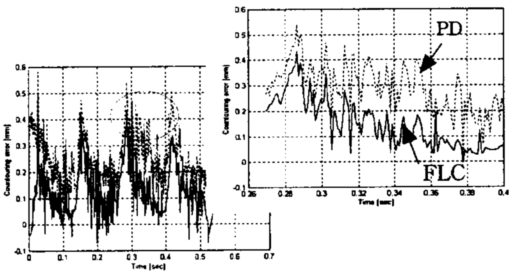

Fig.6 Experimental results
Conditions: feedrate * 0.6

6. CONCLUSION

In this paper, to improve the contour error of XY positioning system, a cross coupled fuzzy logic controller are proposed.

From the experimental results, we can conclude that the contour tracking performance of the Fuzzy Logic Controller (FLC) is much better than that of the conventional PD control regardless of the contour shapes and the feedrates and the FLC is even more robust friction disturbance and the response is faster, the contour error converges faster than the PD control. Cross Coupled Control is equipped simultaneously.

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