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Research Article

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The controller of ball and plate system designed based on FNN

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ABSTRACT

Ball and plate system based on vision is a typical multi-variable nonlinear object, To the question of position and trace control, a based fuzzy multi-variable control combined neural networks is proposed on this paper. The simulation result and real system result of position and trace control shows that our scheme has better performance.

Key words: Ball and plate system; trace control; fuzzy multi-variable control

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INTRODUCTION

Ball and plate system is a typical multi-variable nonlinear object, such as Fig1，which is composed of ball and plate , CCD, motors and controller. Two motors drive plate trundle, CCD is for ball position detection.

It's a problem[1]as Ball and plate system is double IO nonlinear object. To the question of position and trace control, a based fuzzy multi-variable control combined neural networks is proposed on this paper. The simulation result and real system result of position and trace control shows that our scheme has better performance.

Fig. 1: Ball and plate system

CONTROL STRATEGY

X and Y axis perpendicular on the plate, which has two degrees of rotation freedom with the X axis rotate and Y axis rotate. Corresponding to the plate around the X axis rotation angle q1 and q2 around Y axis rotation angle, counterclockwise is a positive angle.

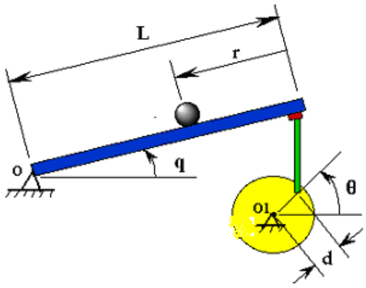

Fig 2: The relationship between the plate angle and motor

It can be proven that if the q is small，the relationship of q1 and the X-axis motor rotationθm1, q2 and the Y-axis motor rotationθm2 can be shown as follows:

$$q_1 = \frac{d_1}{L_1}\theta_{m1}$$
$$q_2 = \frac{d_2}{L_2}\theta_{m2} \tag{1}$$

For Googol ball and plate system used in this paper, d1=d2=23mm. L1=L2=98mm.
Based on Lagrange equation, we can get ball and plate system kinetic model such as follows:
X direction:

$$m_b g r_b \sin q_2 \cos q_1 - m_b r_b[(h+r_b)\ddot{q}_2 - y_b \ddot{q}_1 \sin q_2 - x_b \dot{q}_2^{\,2}$$
$$- x_b q_1 \sin^2 q_2 + (h+r_b)\dot{q}_1 \sin q_2 \cos q_2 - 2 y_b \dot{q}_1 \sin q_2 + \ddot{x}_b] - I_b((\ddot{x}_b / r_b) + \ddot{q}_2) = 0 \tag{2}$$

Y direction:

$$m_b g r_b \sin q_1 + m_b r_b[x_b(\ddot{q}_1 \sin q_2 + \dot{q}_2 \dot{q}_1 \cos q_2) - (h+r_b)(\ddot{q}_1 \cos q_2 - \dot{q}_2 \dot{q}_1 \sin q_2) + \dot{q}_2 \dot{q}_1 (h+r_b)\sin q_2$$
$$- y_b \dot{q}_1^{\,2} + x_b \dot{q}_2 \dot{q}_1 \cos q_2 + 2\dot{x}_b \dot{q}_1 \sin q_2 + \ddot{y}_b] + I_b((\ddot{y}_b / r_b) - \ddot{q}_1 \cos q_2 + \dot{q}_2 \dot{q}_1 \sin q_2) = 0 \tag{3}$$

mb- ball quality

Rb-ball radius
Ib- moment of inertia for ball
h- the distance between plate surface and plate center of rotation
xb- ball X axis coordinate position at the plate
yb- ball Y axis coordinate position at the plate

System can approximate is decomposed into two subsystems, party x and y direction, such as:

$$\begin{bmatrix} \dot{x}_1 \\ \dot{x}_2 \\ \dot{x}_3 \\ \dot{x}_4 \end{bmatrix} = \begin{bmatrix} x_2 \\ B(x_1 x_4^{\,2} - g \sin x_3) \\ x_4 \\ 0 \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ 0 \\ 1 \end{bmatrix} u_x \tag{4}$$

$$\begin{bmatrix} \dot{x}_5 \\ \dot{x}_6 \\ \dot{x}_7 \\ \dot{x}_8 \end{bmatrix} = \begin{bmatrix} x_6 \\ B(x_5 x_8^{\,2} - g \sin x_7) \\ x_8 \\ 0 \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ 0 \\ 1 \end{bmatrix} u_y \tag{5}$$

Among them:

$$B = \frac{m_b}{(m_b + J_b / r^2{}_b)}$$

$$\ddot{q}_1 = u_x \qquad x = [x_1, x_2, x_3, x_4, x_5, x_6, x_7, x_8]^T$$

$$\ddot{q}_2 = u_y \qquad = [x, \dot{x}, q_1, \dot{q}_1, y, \dot{y}, q_2, \dot{q}_2]^T$$

The motor shaft position is tested through the motor with encoder , But between θ and motor shaft there is a reduction ratio n, the encoder output pulse signal, and feedback to drive, drive receives the signals of incremental encoder, Signal by the two road signals (A, B) and the index all the way signal of two-way signal for square wave signals, phase difference between the two is 90 degrees, A signal ahead of B signal motor forward, otherwise the motor reversal. Here an integrator is contained in servo motor model, so the servo motor can be regard as an integrator.

Close loop control of ball and plate system structure is shown in Fig 3:

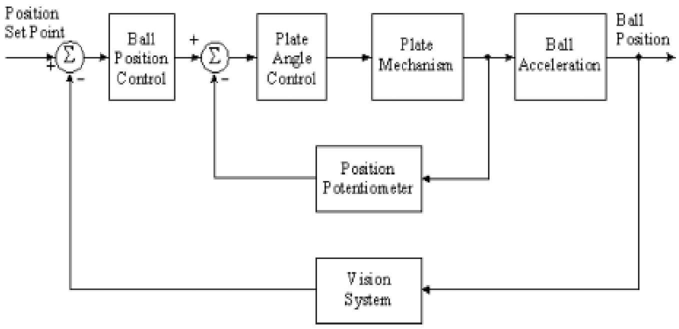

Fig 3:ball and plate system control structure

System working as follows:
(1) System initialization.

(2)Control system began to work. Each control cycle comes to collect a frame image, based on image processing operations to get the ball in the center of mass in the image coordinates.

(3)According to camera calibration of camera parameter matrix, the small ball in the world coordinate system is obtained by the coordinate mapping real location.

(4)According to the result of (3) and the control strategy of calculating motor rotation; Control system is distributed to the actuator control instruction according to the results of the calculation.

Considering the symmetry of x direction and y direction, The following only discuss x direction controller design，Y direction controller is the same as the x direction. The input for the controller $e = [x_d - x]$ and $\dot{e} = [\dot{x}_d - \dot{x}]$, $q_1, \dot{q}_1$, output is u_x 。

The first layer for the blurred layer of the controller，Membership functions are gauss function; $y_i^{(1)}$ is the first layer of the ith node output，

$$y_i^{(1)} = e^{\frac{(x_k - c_i)}{\sigma^2}} \quad \text{（i=1,2….20; k=1，2，3，4）} \qquad (6)$$

The second floor is

$$\text{（}\ y_i^{(2)} = Max\ (\omega_{ij} * y_i^{(1)}) \quad \text{i=j=1,2….20）} \qquad (7)$$

The third floor is $y_k^{(3)} = Min(y_i^{(2)})$ （k=1,2;n=1,…10;j=10(K-1)+n）

Network parameters need to be trained are c_{ij}, σ_{ij}, ω_{ij}, To simplify the calculations, assuming the center and width values of all membership functions are equal， $c_{ij} = \mathrm{c}$, $\sigma_{ij} = \sigma$ .Offline training these parameters, The cost function is selected as the optimal control index function E. Therefore, the parameters of fuzzy neural network controller can be off-line training in accordance with the gradient method:

$$
\begin{aligned}
\omega_{ij}(k+1) &= \omega_{ij}(k) - \alpha_1 \frac{\partial E}{\partial \omega_{ij}} \\
c(k+1) &= c(k) - \alpha_2 \frac{\partial E}{\partial c} \\
\sigma(k+1) &= \sigma(k) - \alpha_3 \frac{\partial E}{\partial \sigma}
\end{aligned}
\tag{8}
$$

α_i is Learning rate.

EXPERIMENTAL RESULTS

A real system experiments has been done combined based on Matlab. Experimental parameters：d=23mm，L=98mm， $m_b = 38g,\ r_b = 15mm$ ，the plate radius is 140mm.

Table 1 ball and plate system parameter list

Number	Parameters	values
1	Outline dimension	600mm*300mm*400mm
2	The motor rated power	24W
3	power	AC220V 50HZ
4	Ball quality	38g
5	Ball radius	15mm
6	plate radius	140mm
7	Reduction ratio	8
8	pixel	768*576
9	Sampling frequency	>25fps

The basic position control achieved within the error 1mm, such as Fig 4，the ball reaches the desired position from the initial position (0,0) (50,50),‘+’ show its trajectory in the Fig 5, x coordinate error is 0.62mm and y coordinate error is 0.56mm while a grid is 1mm in the Fig 5.

Fig 4:initial position（0，0）

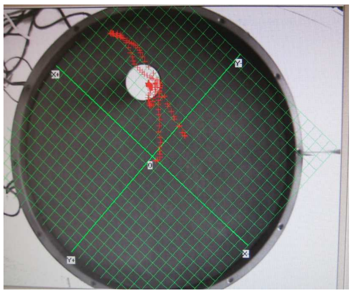

Fig 5:Ball from the initial position reaches a set（50，50）

On this basis, a small ball trajectory control has made, in Fig 5 the ball move from the origin along the x-axis from the movement forward, in Fig 6 the ball move S trajectory from the origin position.

$$y = 0.04 + 0.035 * \sin((\pi / 2)(x / 0.015))$$

While x:0-100mm;

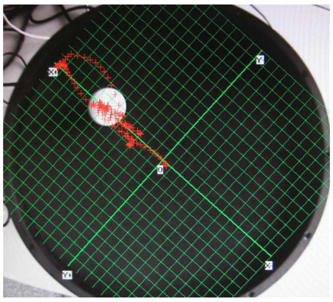

Fig.6: Trajectory control one

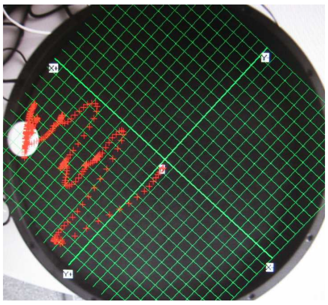

Fig.7.:Trajectory control two Conclusion

CONCLUSION

As ball and plate system is a typical multi-variable nonlinear object, Its characteristics and control methods of research makes sense. To the question of position and trace control, a based fuzzy multi-variable control combined neural networks is proposed on this paper. From the experimental results, reaching the position error of about 0.6 mm, have achieved a more accurate position control and better trajectory control.

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