Performance Analysis of Fuzzy RBF Neural Network PID Controller for Simulation Turntable Servo System

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Abstract
Because simulation turntable servo system is highly nonlinear and uncertainty plants, a fuzzy neural network PID controller is proposed based on the Radial Basis Function (RBF). Up to now, various kinds of nonlinear PID controllers have been designed in order to satisfactorily control this system and some of them applied in actual systems with different degrees. Given this background, the step input and disturbance input simulation experiments are carried out based on MATLAB/SIMULINK tools to evaluate the performances of four different turntable servo controllers, including the conventional PID, the fuzzy self-tuning PID, the neural network PID and the fuzzy RBF neural network PID controller. For further comparison of the four PID controllers, the tracking curves of 2Hz sinusoidal signals and triangular wave signal are given. The comparison results show that the fuzzy RBF neural network PID controller can perform much better and make the tracking error arbitrarily small.
Key words: TURNTABLE, SERVO SYSTEM, FUZZY NEURAL NETWORK CONTROL, RBF NETWORK, PID.

Introduction

Simulation turntable is an important part of the seeker pre-install test system [1]. It carries the animation machine, monitors, optical coupler, control systems and some other parts of display and testing equipment. The movement of simulation turntable can be used to generate azimuth and elevation changes of the missile. The precision and control performance of simulation turntable servo system have a significant impact for successfully completing seeker performance testing and inspection.

Traditionally, conventional PID controller is extensively used in the simulation turntable servo system, because of its simplicity of operation, ease of design, inexpensive maintenance, low cost, and so on [2-4]. However, its control performance is difficult to guarantee when the parameters change or the disturbance exists. In order that the servo system can have good accuracy and control performance in more running mode, more recently, intelligent control and conventional PID control methods are combined to design the position controller of turntable servo system. In Ref [1] a RBF neural network PID control algorithm module is developed, and the control precision has been compared with PID control. In Ref [5] a fuzzy self-tuning PID controllers is introduced and used in the turntable servo system, which shows that the fuzzy PID control strategy is more robust than conventional PID control. Ref [6] proposes a self-organizing fuzzy neural network and its two applications including function approximation and forecast modeling of the wastewater treatment system, the simulation studies demonstrate the presented algorithm is superior in terms of compact structure and learning efficiency. In Ref [7] the PID controller and the fuzzy-neural network are combined and used in robot weapon station servo system, simulation results showed that this controller strategy has high accuracy, good stability, better dynamic and so on.

Although, various methods have been proposed to design the position controller of the turntable servo system, there are not comparative analysis on performance and accuracy of these position controllers. This paper fully considers the characteristics of fuzzy control and neural network control, combines the fuzzy RBF neural network control with conventional PID control and designs fuzzy RBF neural network PID controller of the servo system. The simulation models are built based on the Matlab/Simulink RTW tools, and the step input, sinusoidal input, triangular wave input and disturbance input simulation tests are carried out. The simulation results are analyzed comparing with the conventional PID controller, fuzzy self-tuning PID and the neural network PID controller. The comparison results show that the fuzzy RBF neural network PID controller has better performances in the stability and robust of the simulation turntable servo system.

Model of Simulation Turntable Servo System

Both azimuth axis and pitch axis of the simulation turntable are composed of turntable frames, controllers, AC servo motors, drives and speed reducers. Each axis is individually controlled by double-loop control structure. The single-axis position control block diagram is shown as Figure1. For this control system, the inner velocity loop is controlled by conventional PID controller and the outer position loop is controlled by the fuzzy RBF neural network PID method.

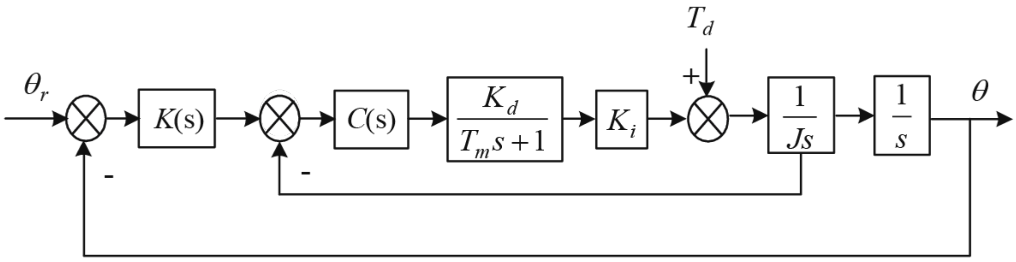

Figure1. Position control block diagram of simulation turntable

In Figure1, $K(s)$ is the main controller of the outer position loop; $C(s)$ is the secondary controller of the inner velocity loop. $\frac{K_d}{T_m s+1}$ is the transfer function of AC servo motor and its driver, where, K_i is the transfer coefficient of driver-motor device, measuring out through experiment; T_m is the electromechanical time constant of driver-motor device. K_i is the transfer function of the reducer, $\frac{1}{Js^2}$ is the transfer function of turntable platform. θ_r is the total load torque viz. disturbance torque. θ_r is the set input value of turntable corner; θ is the actual value measured by the optical encoder.

According to the element parameters of servo system, the open-loop transfer function can be calculated as equation (1):

$$G(s) = \frac{0.29s + 13.2}{0.0000682s^3 + 0.022s^2 + 2.77s + 126.1} \qquad (1)$$

Position Controller of Simulation Turntable Servo System

Conventional PID Controller

Conventional PID is a direct closed-loop control of the controlled object. The specifically structure is shown as Figure2. The control rules of conventional PID controller are:

$$u(t) = k_p e(t) + k_i \int_0^t e(t)dt + k_d \frac{de}{dt} \qquad (2)$$

System error: $e(t) = r(t) - y(t)$

In equation (2): $y(t)$ is the set input value; $y(t)$ is the output value of system.

The tuning method of three parameters k_p, k_i, k_d is mainly used Ziegler-Nichols method, Coohen-Coon method, Astrom method and so on. A set of PID parameters are designed by these method, and the parameters are used to control the object. But, these pre-tuning PID parameters are difficult to achieve satisfactory control effect when the system is a large inertia, nonlinear, time-delay or strong interference one.

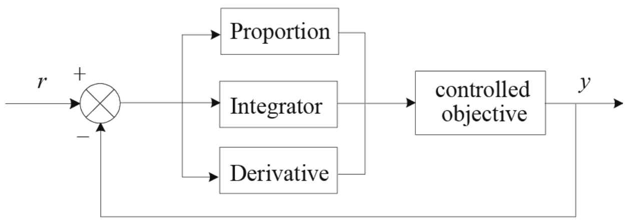

Figure 2. Structure of conventional PID control

Fuzzy Self-tuning PID Controller

The structure of fuzzy self-tuning PID controller [8] is mainly composed of two parts, the PID controller with adjustable parameters and the fuzzy control system, as shown in the Figure3. On the basis of the conventional PID controller, the error $|e|$ and error rate $|ec|$ are taken as input, and the fuzzy inference method is used for PID parameters k_p, k_i and k_d online self-tuning to meet different controller parameters required, so that the controlled object can have a good dynamic and static performance.

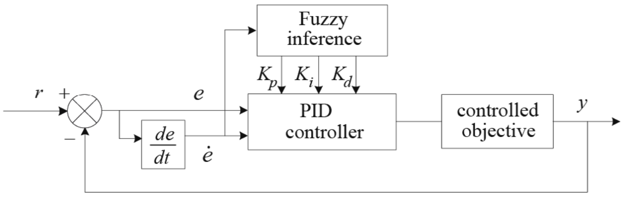

Figure 3. Structure of fuzzy self-tuning PID controller

RBF Neural Network PID Controller

The structure of neural PID with multilayer network is a wide variety, here given the RBF neural network tuning PID control as an example. The block diagram of RBF PID controller for simulation turntable servo system is shown as Figure4. The RBF neural network identifier can identify the approximate model of the controlled object through the input and output data, and use the model instead of the input-output relationship of controlled object. The PID controller parameters can achieve self-tuning by RBF neural network identifier.

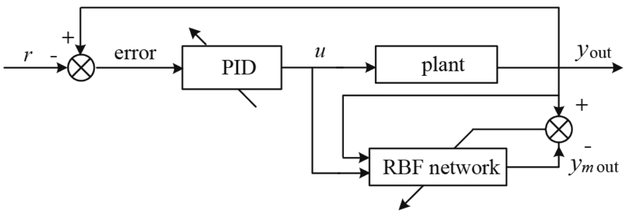

Figure 4. Block diagram of RBF PID controller

Fuzzy RBF Neural Network PID Controller

Configuration of Fuzzy RBF Neural Network PID Controller

The configuration of fuzzy RBF neural network PID controller is shown in Figure5. The controller uses fuzzy RBF neural network to tune the 3 parameters k_p, k_i, k_d of PID controller online, so as to achieve certain performance optimization[9].

In Figure5, *r* is the set input value; *y* is the output value of system. e is the error, ec is the change rate of error, u is the output of PID controller. k_p, k_i, k_d is the output parameters of fuzzy RBF network, also is the input of the PID controller.

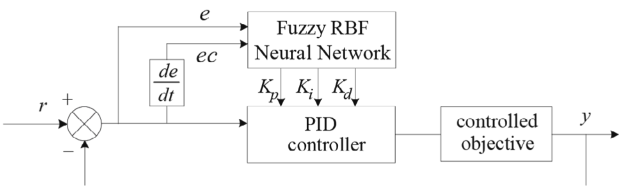

Figure 5. Configuration of Fuzzy RBF Neural Network PID Controller

Fuzzy RBF neural Network consists of four layers: input layer, fuzzy layer, fuzzy reasoning layer and output layer [10]. The connection weights between input layer and fuzzy layer, fuzzy layer and fuzzy reasoning layer are 1, but the weights between fuzzy reasoning layer and output layer need to adjust. A typical structure of fuzzy RBF neural network is shown in Figure6.

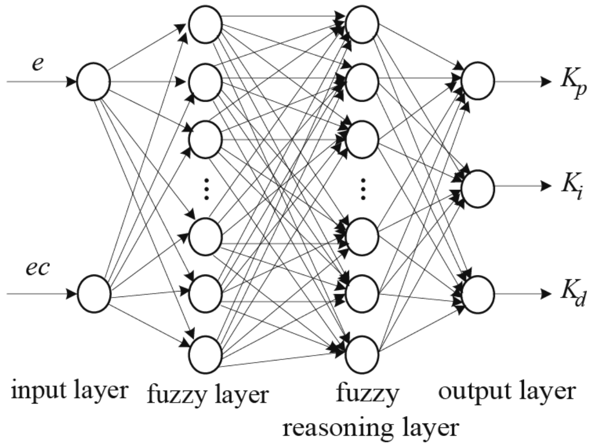

Figure6. Structure of fuzzy RBF neural network

Layer 1 is input layer. Each neuron in this layer represents an input variable, and passes the input value to the next level. Here use error *e* and error change rate *ec* as the input variables. The output of layer 1 is $f_1(x_i) = x_i$, viz. $x_1 = e(t)$ $x_2 = e\ (t)$.

Layer 2 is fuzzy layer. Each neuron in this layer is used to analog a membership function of input variables. The role of fuzzy layer is to calculate fuzzy set membership function for each input language variable. Each node of this layer is the fuzzy subset of *e* and *ec*, each has five nodes, which can be expressed as {positive big, positive small, zero, negative small, negative big}, using {PB, PS, ZO, NS, NB} as symbol. Thus, the fuzzy layer has ten nodes.

According to the characteristics of simulation turntable servo system, here use Gaussian function as the membership function. Its expression is:

$$f_2(i,j) = \exp\left[-\frac{(x_i - m_{ij})^2}{\sigma_{ij}^2}\right] \tag{3}$$

In equation (3), m_{ij} and σ_{ij} are the Gaussian membership functions' mean and standard deviation of the *i*th input variable's the *j*th fuzzy set.

Layer 3 is fuzzy reasoning layer. Each node represents a fuzzy rule, and its action is completing the fuzzy matching of fuzzy rules by connecting the fuzzy layer, or obtaining the corresponding activation strength by combining every fuzzy node. The fuzzy reasoning layer has twenty-five nodes.

The output of node j is the product of all input signals in this node, which can be expressed as equation (4).

$$f_3(j) = \prod_{j=1}^{N} f_2(i,j) \tag{4}$$

In equation (4), $N = \prod_{i=1}^{n} n_i$.

Layer 4 is output layer. The layer output f_4 is the tuning results of k_p, k_i, k_d, can be induced as equation (5). This layer has three nodes.

$$f_4(i) = w \cdot f_3 = \sum_{j=1}^{N} w(i, j) \cdot f_3(j) \quad (5)$$

In equation (5), $w(i, j)$ is the connection weight matrix of output node and node in layer 3. Here, i =1, 2, 3.

The output of fuzzy RNF PID controller is:

$$\Delta u(k) = f_4 \cdot xc = k_p \cdot xc(1) + k_i \cdot xc(2) + k_d \cdot xc(3) \quad (6)$$

In equation (6):

$$\begin{aligned} xc(1) &= e(k) \\ xc(2) &= e(k) - e(k-1) \\ xc(3) &= e(k) - 2e(k-1) + e(k-2) \end{aligned} \quad (7)$$

The incremental PID control algorithm adopted is:

$$u(k) = u(k-1) + \Delta u(k) \quad (8)$$

Learning algorithm of fuzzy RBF neural network

Due to the time-varying and non-linear of turntable servo system, the Delta learning rule is used for online correction of neural network parameters, to make the performance index function J optimal. The function J can be expressed as equation (9).

$$J = \frac{1}{2}[r_{in}(k) - y_{out}(k)]^2 \quad (9)$$

In equation (9), $r_{in}(k)$ and $y_{out}(k)$ denote the desired output and the actual output of the network.

The weights of output layer are:

$$w_j(k) = w_j(k-1) + \Delta w_j(k) + \partial[w_j(k-1) - w_j(k-2)] \quad (10)$$

Where, ∂ is the learning momentum factor, k is the iteration step.

The key of learning algorithm is calculated $\Delta w_j(k)$, which can be induced:

$$\Delta w_j(k) = -\eta \cdot \frac{\partial J}{\partial w_j} = \eta \cdot [r_{in}(k) - y_{out}(k)] \times \frac{\partial y_{out}}{\partial \Delta u} \times xc(j) f_3(j) \quad (11)$$

Here, η is the learning rate.

Simulations and Research

In order to compare the performance of the four controllers: conventional PID controller, Fuzzy Self-tuning PID Controller, RBF neural network PID controller and fuzzy RBF neural network PID controller, the simulation experiment based on MATLAB/SIMULINK kit has been carried out.

When the setting input is step signal, the output responses curls of four controllers are indicated as Figure7. It shows that, the fuzzy RBF neural network PID controller can successfully realize the control of the simulation turntable system. The overshoot is not more than 0.05%, the fuzzy RBF neural network PID can well follow up the input signal and improve the robustness of the system.

When the setting input is 2Hz sinusoidal signal, the tracking curves of four controllers are shown in Figure8. The comparison results show that, the fuzzy RBF neural network PID controller can wonderfully track the sinusoidal signals.

The triangular wave signal tracking curves of four controllers are shown in Figure9. The comparison results show that, the triangular wave signal tracking effect of fuzzy RBF neural network PID controller is also notable.

When the simulation turntable system is subjected to pulse interference, the step response curves of four controllers are showed by Figure10. It shows that fuzzy RBF neural network PID controller has excellent anti-interfere performance and stronger robustness.

It is showed by Figure7, Figure8, Figure9 and Figure10 that the fuzzy RBF neural network PID controller is superior to the other three controllers in terms of response speed, tracking performance, anti-interfere capability, robustness and so on. Its application to the simulation turntable servo system has a good application value.

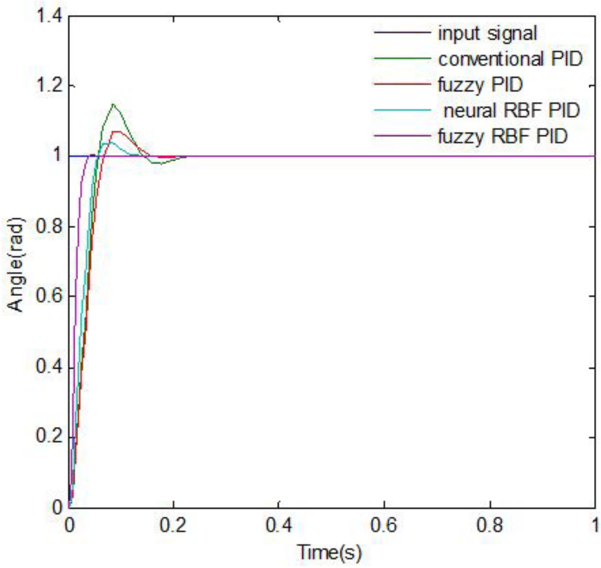

Figure 7. Comparison of step response curves

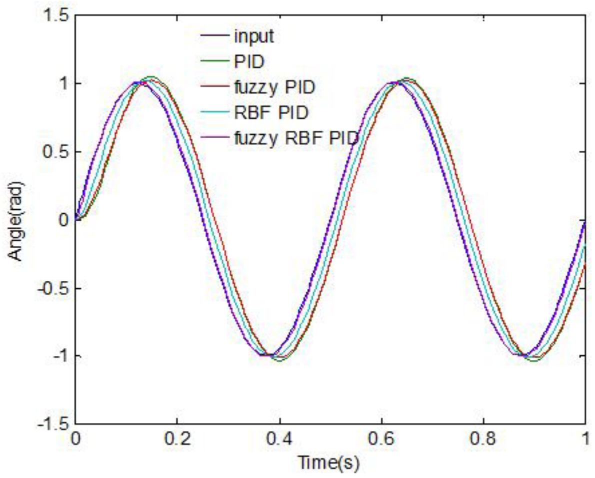

Figure 8. Comparison of 2Hz sinusoidal signal tracking curves

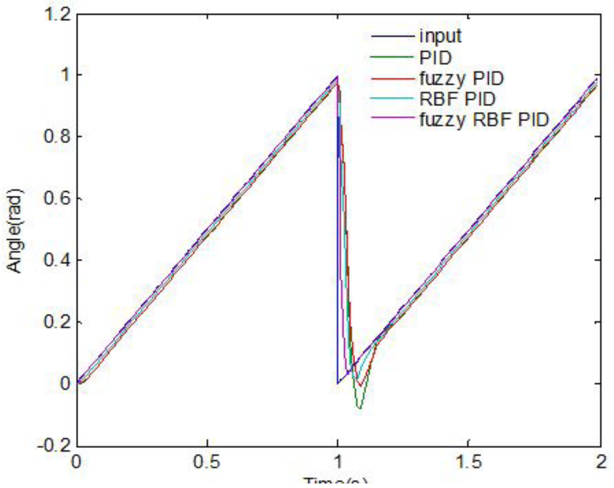

Figure 9. Comparison of triangular wave signal tracking curves

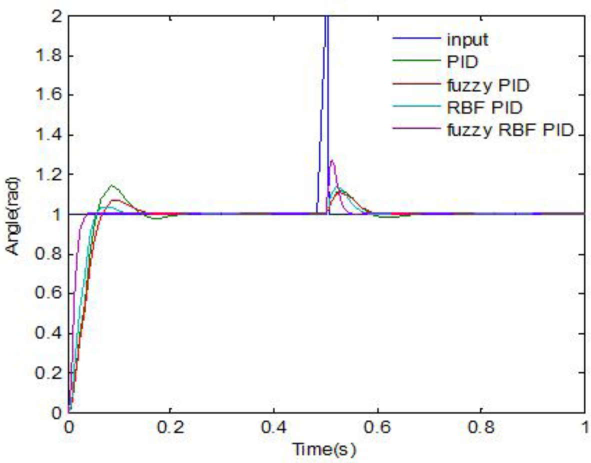

Figure 10. Comparison of pulse interference response curves

Conclusions

This paper has proposed a fuzzy RBF neural network PID controller aiming to the requirement of simulation turntable servo system, and has analyzed the performance of fuzzy RBF neural network PID controller compared with the conventional PID control, the fuzzy self-tuning PID, the neural network PID. The simulation research has been taken, and the simulation results have shown that the fuzzy RBF neural network PID controller can wonderfully track the sinusoidal signals and the triangular wave signal, has superior anti-interfere performance and stronger robustness. As a new method, the fuzzy RBF neural network PID controller can be applied to the simulation turntable servo system excellently.

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