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System Modeling and Simulation Based On Fuzzy Control and Linear Graph Method

Gu Hao[1*], Weiguo Tong[2]
[1]Graduate Student in Department of Automation, North China Electric Power University, Baoding, Hebei, China
[2]Professor in Department of Automation, North China Electric Power University, Baoding, Hebei, China

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***Corresponding author**
Gu Hao

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Abstract: This paper introduces the application of fuzzy control in system modeling and utilizes the Linear Graph of mechanism modeling method to build the system model, and employs Simulink’s S-function to build the system controller and object to conduct simulation. In this paper, the double-ended component system is taken as an example to describe the linear graph theory commonly used in modeling, and the state space equation and the transfer function of the system are established and simulated based on the linear graph method. In the meantime, this paper also analyzes the merits and demerits of linear graph method and other mechanism modeling methods.
Keywords: fuzzy control, Linear Graph, System modeling, Simulink.

INTRODUCTION

Fuzzy modeling refers to approximating unknown nonlinear dynamic systems by using fuzzy systems, thus approximating the whole system. In fact, there are many methods of approximating the unknown nonlinear function, such as AR, model approximation, polynomial approximation, exponential function approximation and so on [1]. These methods are limited to the understanding of the properties of nonlinear.

This paper mainly adopts the mechanism modeling method —line graph method to construct the system model. This method is mainly applied to the establishment of mechanical, electrical, fluid and thermodynamic system models. Based on the law of conservation of energy, it is a graphical mechanism modeling auxiliary method which can connect different systems [2].

This method mainly includes three steps: drawing linear graph, writing tree graph according to a linear graph and then listing equation of state.

System Modeling and Simulation Based on Fuzzy Control

Fuzzy Control Principle

Fuzzy modeling refers to approximating unknown nonlinear dynamic systems by using fuzzy systems, thus approximating the whole system. The Sugeno fuzzy system is very suitable for fuzzy modeling, and the fuzzy toolbox provides functions for training fuzzy systems [3], such as genfis1, genfis2, anfis. This type of Sugeno-type fuzzy inference system can be equivalent to parameters and can adaptively adjust the neural network system, so it is also called adaptive neuro-fuzzy inference system (abbreviated as ANFIS). ANFIS is composed of the front and the back. For example, the rules of a two-input, single-output system are: If x is A1 and y is B1, then z1=p1x+q1y+r1; If x is A2 and y is B2 then z2= P2x+q2y+r2.

Assuming that the input variables are Gaussian membership functions, denoted by g_{xi}(x, ai, bi) and g_{yi}(x, ci, di) respectively (where i=1, 2), then the reasoning process of a two-input, single-output first-order Sugeno fuzzy system is shown in equation respectively (1).

$$z_1 = p_1 x + q_1 y + r_1$$

$$z_2 = p_2 x + q_2 y + r_2 \qquad (1)$$

$$z = \frac{W_1 z_1 + W_2 z_2}{W_1 + W_2} = \bar{W}_1 z_1 + \bar{W}_2 z_2$$

Fuzzy Modeling Process

Fuzzy Inference System Fitting Nonlinear Function

Assuming that the function is f(u)=0.7*sin(πu)+0.3*sin(3πu)+0.1*sin(5πu), let the range of the input u be (-1, 1) and blur it into five regions (that is, set five membership functions), and the fuzzy membership function uses a generalized bell-shaped function [4], the number of ANFIS trainings is 50, and the initial step size is 0.01. The operation result obtained by the simulation program is: mean square error RMSE=0.0105.

At the same time, the simulation results are shown in Figure-1.

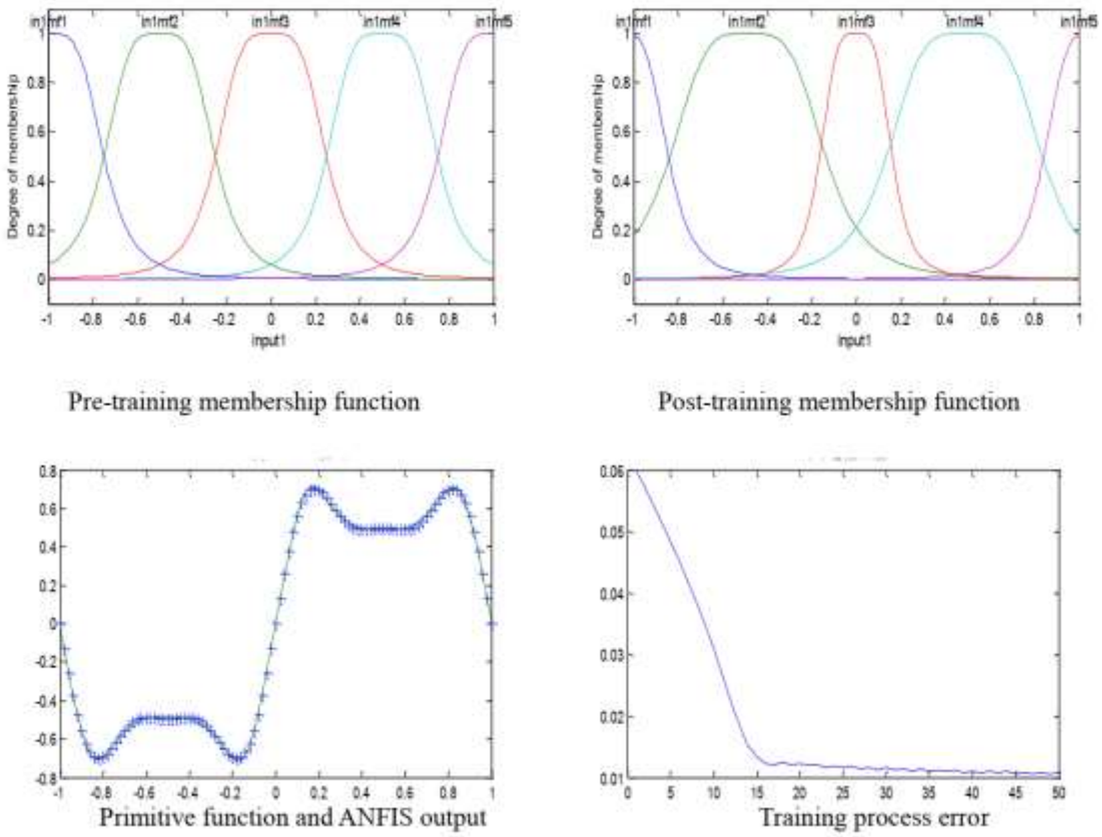

Fig-1: Fuzzy modeling nonlinear fitting effect

ANFIS Approximating Nonlinear Functions

Let the range of input x, y be (-10, 10), and divide it into four fuzzy linguistic quantities. The fuzzy membership function uses a generalized bell-shaped function, and the training data adopts (-10, 10)* (-10, 10) Uniform grid sampling with Δ=0.5. The number of ANFIS trainings set is 200, and the initial step size is 0.1. The fuzzy training results obtained by the simulation program are shown in Figure-2.

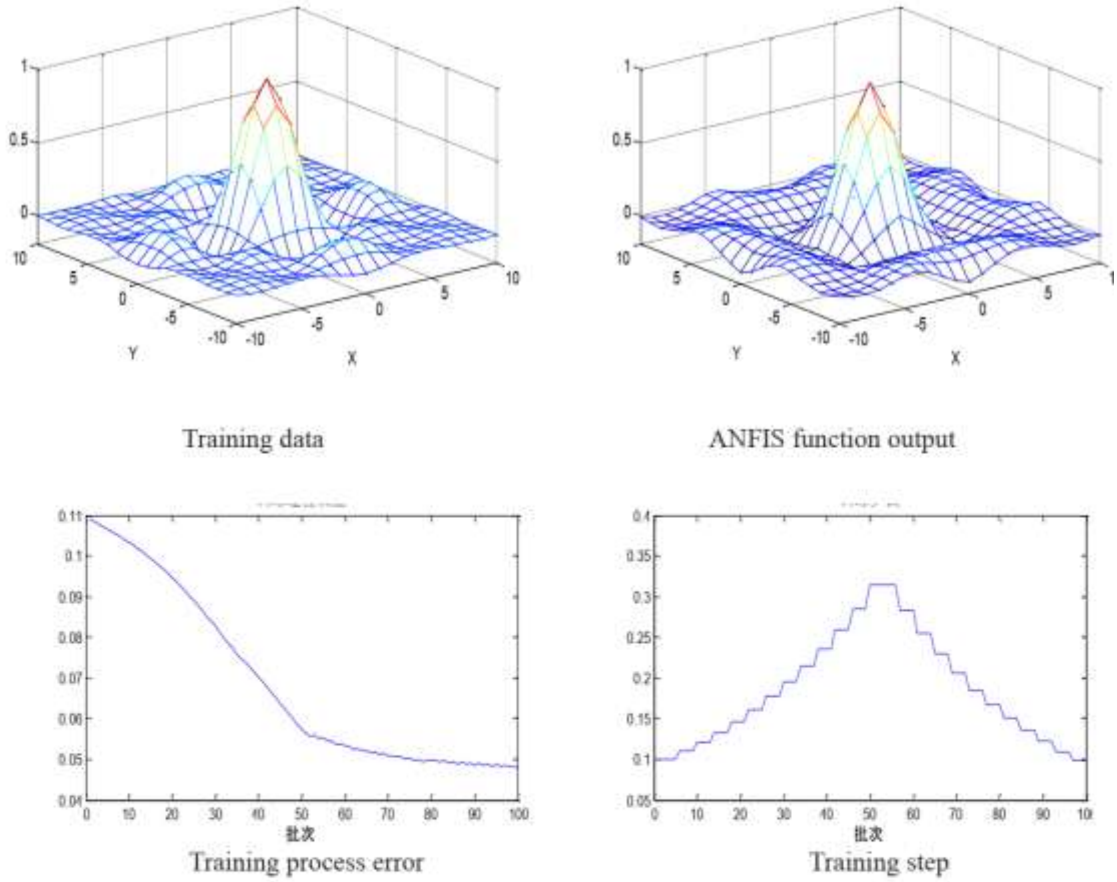

Fig-2: Fuzzy training results

System Modeling and Simulation Based on Line Graph Method

According to the linear graph theory of double-ended components, the DC motor drive system shown in Figure 3 is modeled and simulated. At the same time, the system state space equation and transfer function are established based on the linear graph method [5]. The DC motor is connected to the inertia load J through a reduction gear of a speed ratio n, the input of the system is the motor voltage, and the output is the angular velocity of the flywheel.

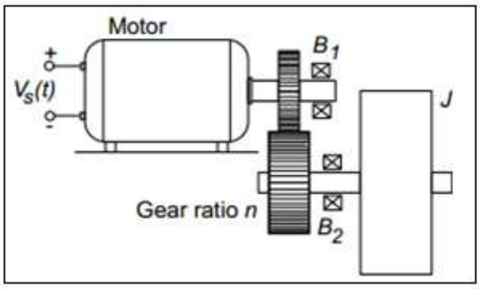

Fig-3: DC motor drive system

System Linear Diagram

The net map consists of edges and vertices. A directed edge corresponds to a component in the actual system. The properties of each edge are reflected by a pair of variables (through variables and spanning variables). The product of the two variables corresponds to the energy change between the two vertices on the edge. According to the model diagram, the linear diagram of the double-ended system is shown in Figure-4.

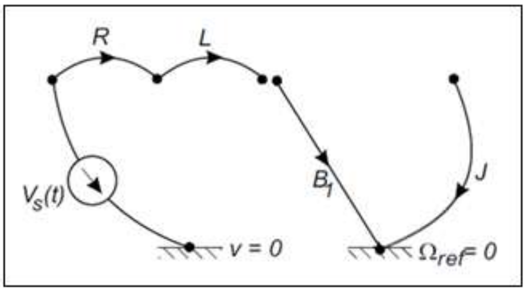

Fig-4: Double-ended System Linear Diagram

It can be known from Fig-4 that B=10, N_1=4, N_2=3, N=7, the order of the system is 2, the state variable is 2, the edge of the tree has N-2=5, and there is an A source. That is, SA=1.

System Graph Tree

The graph tree refers to the graph formed between any two nodes connected by edges and there isn't loop in the whole system according to a linear graph [6]. In the figure, when the number of nodes is N, N-1 tree edges are left, and the other components are connected by dotted lines. The priority order of the margins is: A source - Class A component - Class D component - Class T component - T source. In the graph tree, the main variables of the system are the spanning variables on the tree edge and the through variables on the tree connection. While the secondary variables of the system are the through variables on the tree edge and the spanning variables on the tree connection. That is, one variable of a component is considered as the main variable and the other variable the sub-variables [7]. It can be known from the above analysis that the main variables of the system are Vs, V_R, i_L, V_1, T_2, T_{B1}, Ω_3, T_4, T_{B2}, Ω_J; the secondary variables are is, i_R, V_L, i_1, Ω_2, Ω_{B1}, T_3, Ω_4, Ω_{B2}, T_J. According to the standard tree process generated, the double-ended system standard tree is shown in Figure-5.

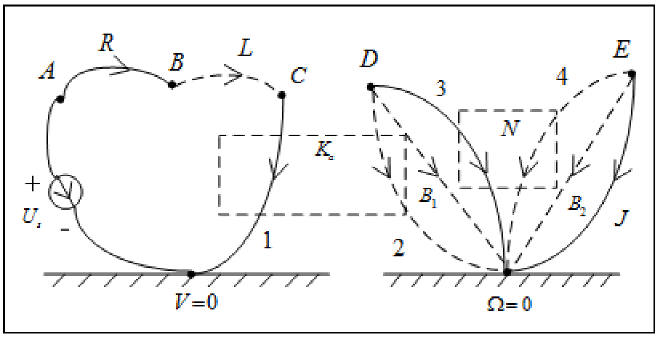

Fig-5: Double-ended system standard tree

State Space Expressions and Transfer Functions

In the standard tree graph, the system's main variables are the spanning variables of the tree edge and the connected through variables; the secondary variables are the through variables of the tree edge and the connected spanning variables ; the order is equal to the number of energy storage components ; the state variable is the spanning variable of the A-type component and the through-variable of the T-type component [8]. Then write the equation according to the number of components (B), the number of nodes (N), the number of A sources (SA) and the number of T sources (ST). The specific steps are as follows:

The first step is to write out the basic equations of B-S (S=SA+ST, SA: A source number, ST:T source number) according to non-source components. Note that the main variable should be written at the left end of the equation and ensure that N main variables appear on the left end. It can be seen from the above system that the number of basic equations is B-S=9, as shown by the formula (2, 3, 4) respectively.

Motor part: $V_R = I_R R \quad V_1 = \frac{1}{k_a}\Omega_2 \quad T_2 = -\frac{1}{k_a} I_1$ (2)

Gear motor side part: $\frac{\mathrm{d}\Omega_J}{\mathrm{dt}} = \frac{1}{J}T_J \quad \frac{\mathrm{d}I_L}{\mathrm{dt}} = \frac{1}{L}V_L \quad T_{B1} = B_1\Omega_{B1}$ (3)

Gear mechanical side part: $\Omega_3 = \frac{1}{k_{.}}\Omega_4 \quad T_4 = -\frac{1}{k_{.}}T_3 \quad T_{B2} = B_2\Omega_{B2}$ (4)

Where $\frac{1}{K_a}$ is the back electromotive voltage constant and N is the gear ratio.

The second step is to write N-1-SA independent continuous equations. The number of nodal equations is N-2-S=4, which is shown in equation respectively (5).

$$i_R = i_L \qquad i_L = i_1 \qquad T_3 = -T_2 - T_{B_1} \qquad T_J = -T_4 - T_{B_2} \tag{5}$$

The third step is to write independent compatible equations of B-N+1-ST (loop equations for links except T sources). There are five loop equations in this system, which are shown in equation respectively (6).

$$U_L = U_S - U_R - U_1 \qquad \Omega_2 = \Omega_3 \qquad \Omega_3 = \Omega_{B_1} \qquad \Omega_J = \Omega_4 \qquad \Omega_J = \Omega_{B_2} \tag{6}$$

The fourth step is to eliminate all the sub-variables in the B-S basic equations, only retaining equation containing n state variables of the B-S basic equitations according to the equations in the previous two steps, and at the same time, organizing n left basic equations into the standard form of the state quation. The state space equation obtained by the above equation is:

$$\begin{aligned}
\frac{d\Omega_J}{dt} &= \frac{T_J}{J} = \frac{-T_4 - T_{B_2}}{J} = \frac{1}{J}\left(-\frac{1}{N}\cdot T_3 - B_2\cdot\Omega_{B_2}\right) = \frac{1}{J}\left[-\frac{1}{N}\cdot(-T_2 - T_{B_1}) - B_2\cdot\Omega_{B_2}\right] \\
&= \frac{1}{J}\left[\frac{1}{N}\left(-\frac{1}{K_a}\cdot i_1\right) + \frac{1}{N}\cdot B_1\cdot\Omega_{B_1} - B_2\cdot\Omega_J\right] \\
&= \frac{1}{J}\left[\frac{1}{N}\left(-\frac{1}{K_a}\cdot i_L\right) + \frac{1}{N}\cdot B_1\cdot\left(-\frac{1}{N}\cdot\Omega_J\right) - B_2\cdot\Omega_J\right] \\
&= -\frac{1}{JNK_a}i_L - \left(\frac{B_1}{JN^2} + \frac{B_2}{J}\right)\Omega_J
\end{aligned} \tag{7}$$

$$\begin{aligned}
\frac{di_L}{dt} &= \frac{U_L}{L} = \frac{U_S - U_R - U_1}{L} = \frac{1}{L}\left[U_S - i_R\cdot R - \frac{1}{K_a}\cdot\Omega_2\right] = \frac{1}{L}\left[U_S - i_R\cdot R - \frac{1}{K_a}\cdot\Omega_3\right] \\
&= \frac{1}{L}\left[U_S - i_R\cdot R - \frac{1}{K_a}\cdot\left(-\frac{1}{N}\right)\cdot\Omega_4\right] = \frac{1}{L}\left(-Ri_L + \frac{1}{K_a N}\Omega_J + U_S\right) \\
&= -\frac{R}{L}i_L + \frac{1}{LK_a N}\Omega_J + \frac{1}{L}U_S
\end{aligned} \tag{8}$$

Ωj/vs=-
(Ka*N)/(B$_1$*Ka^2*R+B$_1$*Ka^2*L*s+B$_2$*Ka^2*N^2*R+J*Ka^2*L*N^2*s^2+B$_2$*Ka^2*L*N^2*s+J*Ka^2*N^2*R*s+1)

The parameter values in the formula are J=1, N=1J, B_1=1, B_2=1, Ka=1, L=1, R=1, and Vs=10V.

System Simulation Curve

The Simulink simulation model built by using the S-function is shown in Figure-6:

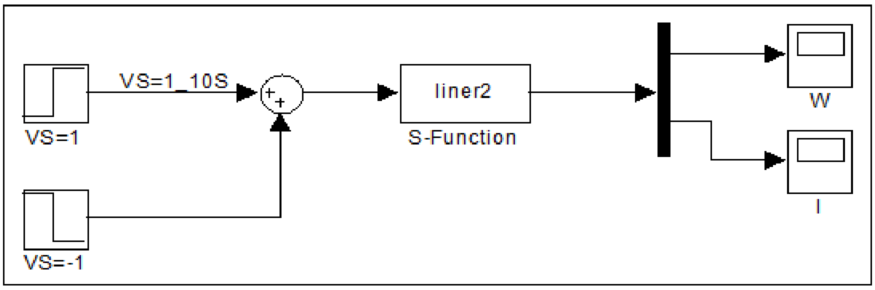

Fig-6: Simulation Model Diagram

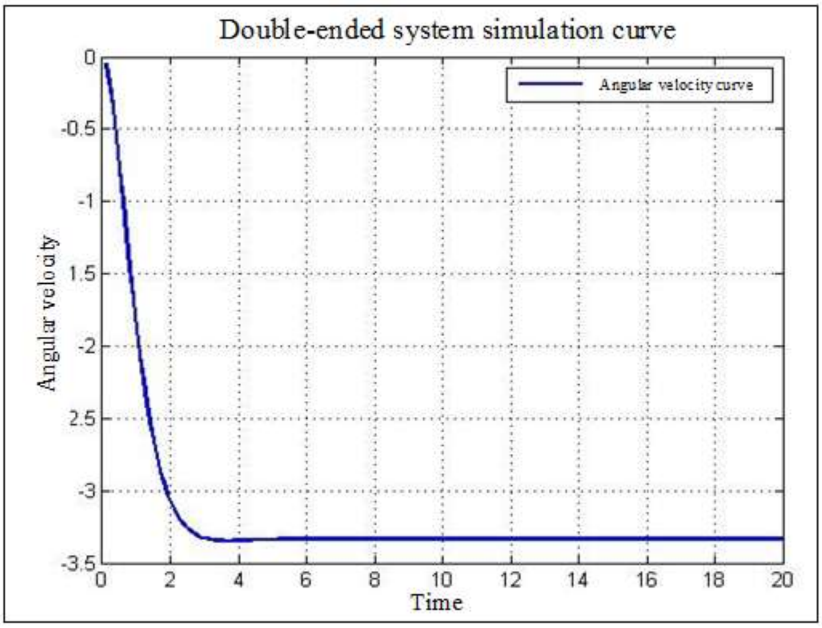

Fig-7: Double-ended System Simulation Results

The system is simulated, and the input is unit step response, then the simulation result of the double-end system is shown in Figure-7:

It can be seen from the structure diagram and response curve of the double-ended system that the motor drive system is a self-balancing system. When 10V voltage is applied to the motor, the electric energy is converted into mechanical energy, and the output of the motor system is converted into the rotational speed of the mechanical system. The final end of the system has a certain speed.

CONCLUSION

Based on the system modeling method of fuzzy control, this paper describes the application process of fuzzy modeling and simulation by fuzzy inference system fitting nonlinear function and the ANFIS approximation nonlinear function modeling case. At the same time, the theoretical analysis of the double-ended components is basically consistent with the MATLAB simulation results. Therefore, compared to other mechanism modeling, the linear graph method has the advantage that without a thorough understanding of the modeling system, the simulation results can be obtained and writing state space equation is simple. Whereas its disadvantage is that previous work is much and complicated and the linear graph method modeling has its limitations.

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