The Application of Fuzzy Control in Computer Control

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***Abstract*—Fuzzy control theory is a computer numerical control theory based on fuzzy set theory, fuzzy language variable and fuzzy logic reasoning. It is widely used for it doesn't require exact mathematical model of controlled object in system design, so that fuzzy control has an advantage in researching high nonlinear system like inverted pendulum. However, rule explosion problem is unavoidable when we use fuzzy control theory to solve some multivariable system control problems such as inverted pendulum. This paper presents the application of the optimal control theory to reduce the input variable dimensions and the rules of the fuzzy controller through designing a fusion function, solving rule explosion problem successfully. The paper also discusses the control effect influenced by quantification factors, promoting performance quality of the fuzzy controller by setting threshold value to make quantification factors automatic regulation.**

Keywords-Fuzzy control; computer control; application; optimization

INTRODUCTION

Fuzzy control is essentially a non-linear control. A major feature of fuzzy control is a systematic theory, and it have a large number of practical applications background. The development of the fuzzy control is initially greater resistance is encountered in the Western. However, in the East, especially in Japan, but has been a rapid and wide application. In recent decades, fuzzy control theory have developed by leaps and bounds to become a very active field of automatic control and fruitful branch. For example, typical applications involving the production and many aspects of life, such as household appliances, air conditioners, microwave ovens, vacuum cleaners, cameras and camcorders. Water purification, in the field of industrial control and fuzzy control of the fermentation process, a chemical reaction kettle, cement kiln.

Fuzzy control is a computer numerical control based on fuzzy set, fuzzy language variable and fuzzy logic reasoning. From the perspective of linearity control and nonlinearity control, fuzzy control belongs to the latter. From the performance of controller, fuzzy control belongs to intelligent control. Moreover, it has become an important and effective intelligent control form at present.

FUZZY CONTROL THEORY

Since fuzzy control is a form of computer numerical control, fuzzy control system is similar to ordinary numerical control system, as shown in Chart 1.

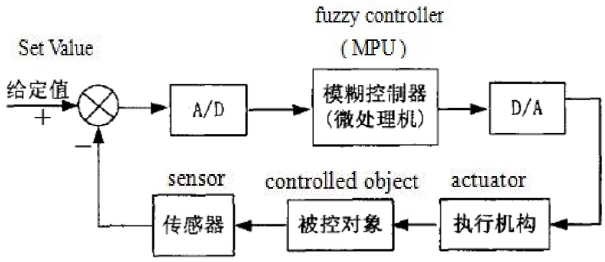

Chart 1 Fuzzy Control System

(1)Fuzzy Controller: This is the core of fuzzy control, and it adopts linguistic "fuzzy controller" based on the knowledge and rule reasoning of the fuzzy control. It's also the characteristic of the fuzzy control system which differs from other automatic control system.

(2)Input/ Output Interface: Fuzzy controller obtains digital semaphore from controlled object through input / output interface, and transfers the digital signal of fuzzy controller through data conversion into analog signals and then send to controlled object. Input / Output interface devices include the necessary level conversion circuit expect A/D, D/A transfer.

(3)Executive Mechanism: It includes AC, DC motors, servo motors, stepping motors, pneumatic control valves, fluid pressure motors and hydraulic valves, etc.

(4)Controlled Object: Controlled object may be certain or fuzzy, univariate or multivariate, with lag or without lag, and also may be linear or nonlinear, time-invariant or time-variant, strongly coupled and disturbed.

(5)Sensor: It is a kind of device which converts controlled object or controlled volume in various processes to a electrical signal. The controlled volume tends to be non-electrical quantity, such as displacement, speed, acceleration, temperature, pressure, flow, concentration and humidity, etc. The sensor plays an important role in fuzzy control system and its accuracy has direct influence towards the accuracy of whole control system.

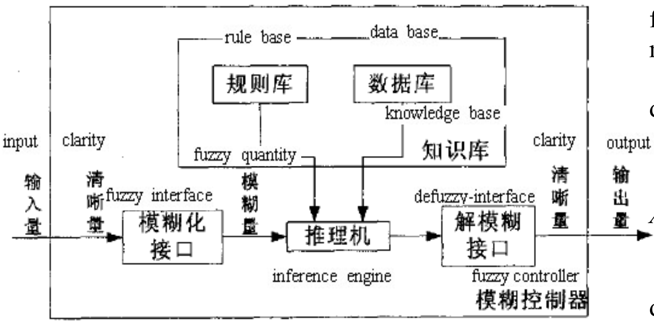

Chart 2 Fuzzy Controller Structure Chart

Fuzzy controller is the core of the fuzzy control system, as shown in Chart 2. The fuzzy controller is commonly implemented as a software programming, and the general procedure to realize fuzzy control is as follows:

(1)Determining the input and output variable of the fuzzy controller, that is controlled variable;

(2)Designing control rules of the fuzzy controller;

(3)Fuzzification and Defuzzification;

(4)Selecting the universe of input and output variables of the fuzzy controller and determining the parameter of the fuzzy controller, like quantitative factor and scale factor;

(5)Programming application of fuzzy control algorithm;

(6)Choosing sampling time of the fuzzy control algorithm properly.

THE FUZZY CONTROL METHOD OF THE INVERTED PENDULUM

Inverted pendulum system is a higher-order system of complex, nonlinear and unstable. The control of inverted pendulum is a typical problem of the theory and application of control. When we discuss the fuzzy control of the multivariable nonlinear system like inverted pendulum, one of the problems we meet is rule explosion. For example, there are four involving state variables in control of the single inverted pendulum, using fuzzy divide the universe of each variable to seven fuzzy sets, and complete inference rule base contains 7^4=2401 inference rules. While there are six state variables in the double inverted pendulum, and the inference rules will be 7^6=11 7649, thus, it is obviously impossible to realize so many rules.

In order to work the problem out, Zhang Naiyao and others put forward the fuzzy control plan of double closed loops of the inverted pendulum, that is, inner loop controls angle and outer loop controls displacement. This method is extended to triple inverted pendulum system by Fan Xingzhe and others, and they presented two cascade fuzzy control methods to solve rule explosion in fuzzy control of the multivariable system such as inverted pendulum.

The paper imitates the human ideas of simplifying problems, translates single complicated control strategy into multistage simple control strategy nest, and combines optimal control theory with fussy control strategy. Adopting

fusion technique to design a linear fusion function and merging several variables into composition error E and composition error rate of change EC deeply simplify the design of the fuzzy controller.

FUSION TECHNIQUE AND FUSION FUNCTION

A. Fusion Technique

Theoretically, there's an obvious coupling among displacement r, speed $\dot{r}$, pendulum angle θ and angle $\dot{\theta}$. Controlling zero position range of the cart motion as well as keeping the pendulum should have an overall consideration on mechanical relationship between cart and pendulum. As for multi-factor problem, adopting step-by-step processing can simplified the solution. This kind of thinking applies to the design process of the multiple inputs fuzzy controller. Supposing to design high dimensional input variable *X* that map into the fuzzy controller of output variable *Y*, you may adopt multilevel control for it is a little bit difficult to design single stage fuzzy strategy from *X* to *Y*, so that transfer single stage fuzzy strategy to multilevel control strategy nest:

$$Y = F_2[F_1(X)] \quad (1)$$

Use algorithm $F_1(X)$ to handle input variable *X*, then control output by algorithm $F_2()$. If the out dimension of $F_1(X)$ is less than the dimension of *X*, the controlling of $F_2()$ could be simplified. It can be seen that algorithm $F_1(X)$ finishes problems combination and collection through the relativity of system state and the integration of input information, which is called "Fusion Function". Algorithm $F_2()$ is called fuzzy action function for its fuzzy inference based on reduction. The method of multiple inputs fuzzy controller based on information fusion is to combine and collect information and realize the simplification of control problem through fusion function.

B. Design of Fusion Function

The double inverted pendulum is typical Multiple-Input and Single-Output (MISO) system, as shown in Chart 3. Formula (2) is the equation of state that the double inverted pendulum can be approximately considered as linear system. We design a linear fusion function, with taking advantage of the characteristic that output information can fusion together directly in fusion function linear system, and merge six dimensional state variable of the double inverted pendulum into composition error E and composition error rate of change EC.

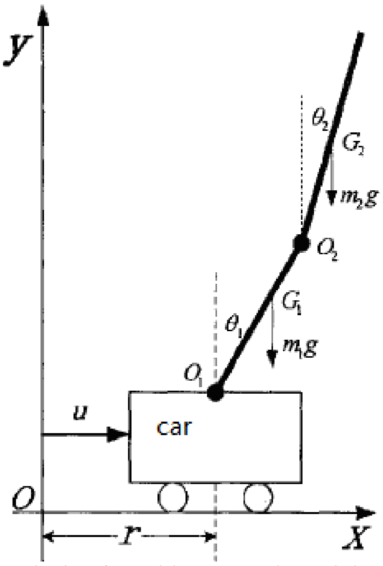

Chart 3 Analysis of Double Inverted Pendulum Motion

$$\begin{cases} \dot{X} = AX + Bu \\ Y = \begin{pmatrix} r \\ \theta_1 \\ \theta_2 \end{pmatrix} = CX \end{cases} \qquad (2)$$

Steps of Fusion Function:

(1) Make use of optimal control theory to figure out a group of feedback matrix K which keeps linear model of the double inverted pendulum system stable:

$$K = [K_r, K_{\theta_1}, K_{\theta_2}, K_{\dot{r}}, K_{\dot{\theta}_1} . K_{\dot{\theta}_2}] \qquad (3)$$

According to the form of the linear state feedback:

$$u = KX^T \qquad (4)$$

Make use of Linear Quadratic Regulator (LQR) to design a state feedback matrix of the double inverted pendulum equation of state.

Optimal Control Performance Indexes Function:

$$J = \int_0^\infty (X^T QX + u^T Ru)dt \qquad (5)$$

Minimum the Performance Indexes Function (5), you can get:

Solve the following Ricatti algebraic equation:

$$A^T PA - A^T PB(B^T PB)^{-1} B^T PA + Q = P \qquad (6)$$

You can get Matrix P.

Note: Parameters selection of LQR. Matrix Q and matrix R balance the weights of input and quantity of state, and deeply influence dynamic property of closed loop system. In inverted pendulum system, for state vector X and control vector *u*, Q and R weight the relative importance of their performance measurement. The relationship among parameters of Q and R, following speed and angular velocity is coupled so that we should select comprehensively. In general, the controlling force and angle decrease and the following speed slow down when R increases. When some element adds relatively in matrix Q, the response speed of corresponding state variable increases and response speed of other state variables decrease. For example, the increase of elements Q to angle θ makes the decrease of θ change range, while response speed of displacement *r* slows down; the increase of elements Q to *r* makes increase of θ change range, and tracking speed of displacement *r* changes fast.

In the control procedure of actual system, we let:

$$Q = \begin{vmatrix} 1000 & & & & & \\ & 500 & & & & \\ & & 800 & & & \\ & & & 1 & & \\ & & & & 1 & \\ & & & & & 1 \end{vmatrix}; \quad R=1$$

Get State feedback matrix K by calculation:

$$K = [17.32, 111.53, -202.89, 18.94, 2.74, -36.82]$$

(2) Use State feedback matrix K to Design fusion function $F_1(X)$:

$$F_1(X) = \begin{pmatrix} \frac{K_r}{\|K\|_2} & \frac{K_{\theta_1}}{\|K\|_2} & \frac{K_{\theta_2}}{\|K\|_2} & 0 & 0 & 0 \\ 0 & 0 & 0 & \frac{K_{\dot{r}}}{\|K\|_2} & \frac{K_{\dot{\theta}_1}}{\|K\|_2} & \frac{K_{\dot{\theta}_2}}{\|K\|_2} \end{pmatrix} \qquad (7)$$

And: $\|K\|_2 = \sqrt{K_r^2 + K_{\theta_1}^2 + K_{\theta_2}^2 + K_{\dot{r}}^2 + K_{\dot{\theta}_1}^2 + K_{\dot{\theta}_2}^2}$

According to the parameter of the double inverted pendulum, get $F_1(X)$ by calculation:

$$F_1(X)=\begin{pmatrix} 0.0736 & 0.4696 & -0.8620 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0.0805 & 0.0116 & -0.1564 \end{pmatrix}$$

(3) Get composition error E and rate of change EC by input variable X and $F_1(X)$:

$$\begin{bmatrix} E \\ EC \end{bmatrix} = F_1(X)X^T \tag{8}$$

CONCLUSION

The double inverted pendulum is a typical multiple inputs, nonlinearity and strongly coupled system. It reduces the input dimension of the controller by designing fusion function, and solves the rule explosion problem we meet when we use fuzzy control to work out multiple inputs system. It makes possible to design practical fuzzy controller, which is beneficial to realize computer simulation and programming.

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