Advance of Systematic Design Methods on Fuzzy Control[1]

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Abstract: The heating, ventilation and air-conditioning (HVAC) system possesses some characteristics such as multi-parameters, nonlinear, and coupled parameters. Aimed at control problems, the author targets real-time fuzzy control and research systematically via the fuzzification method, fuzzy inference method, fuzzy control rules online obtaining and optimizing method, self-organizing fuzzy control method, and fuzzy predictive control of a time-delayed process. This paper will briefly introduce previous research results.

Key words: HVAC system; fuzzification; fuzzy logic inference; self-organizing fuzzy control; fuzzy predictive control

1. INTRODUCTION

From ON/OFF double-position control method occurred in 1960s, automatic control of HVAC has been developed to the Digital Direct Control (DDC), which control algorithm is mainly PID control method, and self-adjusting control method based on the traditional control algorithm. However, HVAC system is characterized by multi-variables, long delay time, distribution parameters, coupled variables and nonlinear process, which causes that it is very difficult to establish the exact mathematical models of HVAC system. Then, fuzzy-neural network control, which is based on knowledge of experts and experience of operators, becomes major research areas in HVAC. Many research results indicate that fuzzy-neural network control is an effective method to solve control problems of HVAC. In multiple input and multiple output fuzzy control aspect, Tobi and Hanfusa creates multi-input and multi-output fuzzy controller by setting temperature and moistness of air conditioning system as input variables, and the controlling valve of heater, cooling coil, and moistener as output variables[1].Albert builds multi-input and multi-output dynamic parameter identification/controller of air conditioning unit by using neural network[2], simulates and analyses the dynamic response characters and energy consumption in fuzzy control and PID control. In complex fuzzy control of air conditioning system aspect, Huang and Nelson research the fuzzy control problem of complex building air conditioning system[3,4], which is composed by VAV air conditioning system, refrigerating system and room thermodynamic system. They put forward the method to build fuzzy rules model, which means fuzzy model should be symmetric with a center point. Simulation and test prove this method of building model effective. Then, they put forward rules model self-adjusting fuzzy controller by using phase plane analysis[5], and realize adjusting fuzzy control rules by using reference trace in phase plane. Simulation and test prove that this method has better control performances. Besides, Qingwei Chen puts forward the laminar hierarchical fuzzy control method in workshop air conditioning system by combining laminar hierarchical control and fuzzy control[6]. In fuzzy model parameter identification aspect, Guoliang Ding builds the fuzzy model of compressor thermal character by combining fuzzy model and traditional mechanics model. Results of simulation indicate that mixed building model method has better precision and general performance than traditional model and simple fuzzy model[7]. Jiejia Li introduces wavelet neural network into fuzzy control, which improves fuzzy control performances, considering sufficiently random disturbance and the impact on system in air conditioning control[8], when they solve fuzzy model parameter identification in VAV air conditioning

1 Supported by National Natural Science Foundation of China(50578049)

system. In fuzzy rules online obtaining aspect, the author puts forward Mamdani rules double stages obtaining and self-organizing fuzzy control method and model reference rules self-organizing fuzzy control method of time delay thermal systems, and realize the fuzzy control course of air system and water system in radiator thermal performance test-board[9~11].

We can know that fuzzy control has been used widely to automatic control of building HAVC. In design methods, fuzzy control has been developed from basic fuzzy control method to fuzzy PID, parameters self-optimizing, fuzzy neural network, fuzzy genetic algorithm, and wavelet fuzzy control[8,12-15].In order to accelerate the application and development of fuzzy control in refrigerating and air conditioning field, the author has researched systematically fuzzification method, fuzzy inference method, fuzzy control rules online obtaining and optimizing method, self-organizing fuzzy control method, fuzzy predictive method of time-lag process so many years. This paper will introduce previous research results briefly.

2. FUZZIFIER WITH FUZZY VECTOR REVISED BY TRUE VALUES

Fuzzification means to map an actual accurate value of physical space to fuzzy set of fuzzy inference space. In order to meet the requirement of different fuzzy logic inference for fuzzification results, various fuzzification methods produces different results, such as fuzzy vector and single membership value[16].

Compositional Rule Inference (CRI)[17,18] and Characteristics Expanding Inference (CEI)[19] demand that the premise of the fuzzy control rules must be fuzzy vector. Intensity Transfer Inference (ITI)[20], Truth valued flow Inference (TVFI)[21] and Functioning Fuzzy Subset Inference (FFSI)[22] demand that the premise must be single membership value

At the same time, one fuzzy logic inference could mate various fuzzifiers which would influence performances of fuzzy controller greatly.

The paper[23] firstly generalizes systematically existing fuzzification methods, such as single point fuzzy set, nearside round numbers, membership value linear interpolation, and single membership value[24~27]. Then, puts forward a fuzzifiers with fuzzy vector revised by true values, which means transferring an actual accurate value to fuzzy vector by revising and merging the true value of an actual accurate value in functional fuzzy subset.

Finally, in CRI, finishes fuzzy control simulation of the first order inertia time-lag steady system by using different fuzzifications. Results indicate that this method could improve performances of fuzzy controller with CRI, and erase the steady-state error with the method of nearside round numbers.

3. FUNCTIONING FUZZY SUBSET INFERENCE METHOD

Fuzzy logic reasoning is the base of fuzzy control. For positive fuzzy reasoning problems, the papers[17-21] put forward individually CRI, ITI, CEI, TVFI and FFSI.

CRI firstly calculates general fuzzy implication relationship, then calculates the composition of fuzzy value from actual value and general fuzzy relationship. Finally computes the accurate value of controlled variable. In one time of fuzzy logic reasoning process, CRI has several shortcomings, such as enormous calculations, complex inference. So it is not suitable for real-time control, especially for quick time-variant controlled systems. Then the paper[19] puts forward CEI, which indicates that approximate inference is the transfer of characteristics coefficient. This method need not calculate total fuzzy implication relationship, and simplify inference calculations greatly. But also inference result is the same to CRI. Based on CEI, Peizhuang Wang and Hongmin Zhang[21] put forward TVFI, which indicates that inference is the transfer of truth value and further simplified.

The transfer of actual value in fuzzy implication relationship is not linked to all fuzzy subsets and fuzzy control rules, which is an existing fact in Boolean logic inference and approximate inference, in real-time fuzzy control process.

For the characters of real-time fuzzy reasoning, the paper[22] defines firstly functioning fuzzy subset and functional fuzzy control rules, and puts forward the extraction method in real-time control. Then, according to the mechanics of generating, transferring and receiving truth value, it puts forwards functioning fuzzy subset inference, namely FFSI, compares and analyses the inference results of FFSI and CRI, and develops digital single-chip fuzzy controller based on FFSI. Finally, it realizes fuzzy control tests for indoor temperature by using this inference method.

4. METHODS OF ON-LINE OBTAINING AND OPTIMIZING FUZZY CONTROL RULES

The obtaining and optimization for fuzzy control rule model are the key process for improving performances of fuzzy controller. In real-time fuzzy control process, it is more important to obtain fuzzy control rules on-line. So, the author puts forward on-line obtaining methods individually for Mamdani rules and Takagi-Sugeno rules[10,11], and puts forward optimization method which is based on fuzzy set compatibility[28].

4.1 On-Line Obtaining Method for Mamdani Fuzzy Rules

In fuzzy control, for simple control process, we could build effective control rules by generalizing the experiences of operators and experts in this field. For the complex process with nonlinear and long time-lag, it is difficult to build perfect control rules which could not meet satisfied control effect. One method for solving this problem is to vest self-learning ability for fuzzy controller, so that which could auto-obtain and auto-correct fuzzy control rules according to control objective. So, self-organizing fuzzy controller gains widespread attention[29-34]. And Procyk and Mamdani firstly put forward self-organizing fuzzy controller in 1978[35], and many literatures have researched this kind of fuzzy controller since then[36,37].

Since it is difficult to build initial rules which maybe include the rough and redundant rules for complex control process, the author puts forward Mamdani rules double stages self-organizing fuzzy control method[10], emphasizing on on-line obtaining for Mamdani fuzzy rules. This means to add correct rules module based on basic fuzzy controller, and to realize initial extraction and on-line accurate parameter identification by judging past functional fuzzy control rules and the consequence correcting variable. The analysis of simulation result indicates that this method not only gains satisfied rules model, but also shortens on-line self-organizing time, and improves performances of fuzzy controller, based on correct rules and functional fuzzy subset inference.

4.2 On-Line Obtaining Method for Takagi-Sugeno Fuzzy Rules

When the amount of premise variants is big, the number of Mamdani rules rises as exponential curve, and causes dimension disaster. However, Takagi-Sugeno rules, which are suitable for solving MIMO problems, could generate nonlinear function set to describe dynamic character of controlled system by using a small amount rules[38-44].

The author describes Takagi-Sugeno fuzzy rules with self-adapting fuzzy neural network, and realizes cluster obtain of the medium value, width, and the consequence in Takagi-Sugeno fuzzy rules, by using self-learning character of neural network and subtraction cluster algorithm. The control simulation result of inverted pendulum and second-order time-lag system indicates the practicability of on-line obtaining method for Takagi-Sugeno fuzzy rules, which supplies new path to identify on line and effectively control the dynamic mathematic model of complex process.

4.3 Optimization Method for Fuzzy Control Rules Based on Fuzzy Set Compatibility

The design of fuzzy control model should not only meet the compatibility and completeness of model[45-47], but also reduce the roughness and redundancy, and keep proper reciprocal effect among rules[47]. For simple controlled system, the design of fuzzy control mode could satisfy former requirements basically. For complex controlled system, although reciprocal effect among rules may be controlled by setting membership function, the fuzzy control rules model, which is built according to empirical black-box input and output characters of controlled objective, could cause huge rough and redundant in order to meet the compatibility and completeness of model. So we must delete the roughness and redundancy of the fuzzy control rules, or optimize them.

Peizhuang wang and Shibo Lou put forward the conditions of fuzzy control rules completeness in 1982[48]. In order to describe the reciprocal effect among rules, Yongyi Chen puts forward the conception of "Closure of Rules Recurrence", and gives methods to measure and modify the reciprocal effect among rules. The setting of membership function may reflect the completeness of model. In 1965, Zadeh indicated that we should avoid some fuzzy sets whose membership function is double hump or whose membership value is too small, which requires normal prominent fuzzy sets[49].

Based on fuzzy control rules compatibility[47], the paper puts forward the conception of fuzzy control rules compatibility by leading in the conception of fuzzy set approximate degree [28]. Then it perfects the conception of compatibility and the method to quantitative assessment by analyzing the character of fuzzy control rules tables. Finally, for single order inertia time-lag steady system, this paper gives the optimization process of rules model and the optimization method of self-optimizing fuzzy control rules[50]. The simulation result indicates that this method could increase performances of fuzzy control system.

5. RULES SELF-ADJUSTING FUZZY CONTROL METHOD BASED ON TRACE CHARACT-ERS OF PHASE PLANE

In design of fuzzy controller, phase plane is a comprehensive method to analyze the stability of fuzzy control system[51,52], At the same time, phase plane could increase performances of fuzzy control system by adjusting the values of error, error difference and control quantity, according to characters of phase plane response trace in control system.

Huang and Nelson put forward the modified method for initial fuzzy control rules by analyzing dynamic response process of fuzzy controller with phase plane in 1994. Modified method erases the oscillation and limit loop, shortens greatly convergence time of fuzzy control system. Now this method is used widely in air-conditioning fuzzy control system[3,4]. Huang 和 Nelson put forward self-adjusting fuzzy controller by using phase plane method in 1999[5]. Firstly, they divide the phase plane into several zones according to response trace on phase plane of fuzzy control system. Then, they give the ideal response trace of fuzzy control system from start point to end point, and define several reference points. Finally, they realize to adjust fuzzy control rules by using the distances from actual control response trace to reference points at different zones. The results of simulation and test indicate that this method has better control performances, but the design and calculation of which are complex.

The paper[53] puts forward the conceptions of real-time characteristic vector and real-time characteristic vector include angle of response trace on phase plane, by analyzing characters of response trace on phase plane of fuzzy control system. Based on analyzing the character of real-time characteristic vector include angle, it puts forward the modified method for the consequence of fuzzy control rules. It adds many models on basic fuzzy controller, such as performances assessment and rules adjuster. This paper designs rules self-adjusting fuzzy controller, and puts forward the method of rules self-adjusting fuzzy control based on characters of response trace on phase plane. The simulation results indicate that this method may reduce the overshoot and transition time of fuzzy control system, and increase the rate of convergence.

Besides, the former online obtaining and corresponding control method for Mamdani rules and Takagi-Sugeno rules, also realize self-adapting fuzzy control process. The author would not give unnecessary details here.

6. NEURAL NETWORK MULTI-STEP PREDICTIVE FUZZY CONTROL METHOD OF TIME-LAG PROCESS

The control problem of long time-lag process always is one well-known puzzle in automatic control field. Although, error difference could reflect quantify current changing direction and size of controlled process state variable so that fuzzy control may have some predicted control ability to pure time-lag system, it could not control effectively long time-lag system when τ/T_m>0.5. When the mathematic model of controlled process is known, we could adopt Smith forecaster, Kalman filter, and Smith-Fuzzy controller to solve this problem, also control predicatively by using prediction model of time series. But for multivariable nonlinear long time-lag system, there are some serious difficulties by using former method. By comparison, neural network shows obvious dominances, which has optimum approach nonlinear mapping capability.

The papers[54,55] firstly analyze the dynamic response character of BP network and Elman network identification model, and observe the character of multi-step predictive. Then they introduce fist order and second derivative input at τ-1 to input layer, and put forward neural network multi-step predictive fuzzy control method and model of time-lag system. Finally, linking with fuzzy control, they put forward neural network multi-step predictive fuzzy control method of time-lag system. The control simulation for thermal process with steady and variable setting value indicate that this method has better predictive performance character.

7. CONCLUSIONS

Since E. H. Mamdani used fuzzy control in steam engine in 1974, the design method of fuzzy control experienced two stages with obvious characters. One is traditional fuzzy control design period which is directly depended on people’s experiential knowledge. This stage is from 1970s to 1990s medium-term. In this period, people use their experiential knowledge directly to design fuzzy controller, then adjust the fundamental parameter of the fuzzy controller, such as quantizing factor, scale factor, value range, consequence, membership function. The traditional design method of fuzzy control sufficiently displays its superiority to the classical control and modern control theory, when it is used to solve complex control problems which are unable or difficult to establish the precision mathematical model for controlled objective. But for the lack of the mathematical model of controlled objective, we are not able to analysis the stability and performances index of the controlled system, and not to simulate more accurately. The design of the controller severely depends on the experiential knowledge of experts, which is the shortage of the traditional control design method.

So, the design method of fuzzy control enters into the second stage, the modern fuzzy control design method, this method build up the mathematical model of controlled objective as accurately as possible, analysis the stability and performances index of the controlled system, and to simulate. Then this method designs the fuzzy controller. This stage appeared mainly in the 90s medium-term. Obviously, the development of fuzzy control undergoes a process from basic fuzzy controller to self-adapting fuzzy controller. Then it absorbs the advanced idea from classical control and modern control theory, and enters into the stage of modern fuzzy control, but in this aspect there are much research work needed to do.

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