Study on Fuzzy-Extension Control System for Marine Steering

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Abstract—**Automatic marine steering is an integral part of intelligent vehicle control system. It includes course keeping and course changing. Its main purpose is to ensure that ships sail in the given direction automatically in spite of changes in sea conditions, wind and other disturbances. Fuzzy control is the well-known fact that fuzzy logic systems need no accurate mathematical models of the system under control. Extension logic, based on extension set, is to research the contradictory problem. The combination of extension theory and control theory brought a new type of intelligent control --- extension control. This paper presents fuzzy-extension control method for marine steering. The paper established the model of fuzzy-extension control system and studied the design of fuzzy-extension controller. Simulation results demonstrate that the control method is valuable.**

***Keywords*—fuzzy control, extension control, marine steering, fuzzy-extension controller**

I. Introduction

Automatic marine steering system is one of the most important instruments in ship, and its main purpose is to ensure that ships sail in the given direction automatically. The conventional ship steering system is a SISO (single-input single-output) control system in the sense that the heading (yaw angle) of the ship is measured by a gyro compass and fed back to a PID control system (auto-pilot). PID controllers have been widely used in the control of ship steering. The main problem in using these systems is that conventional PID autopilot couldn’t obtain and maintain optimum control because of lacking the capacity to dynamic character or was hard to tune the controlling parameters. Furthermore, it was difficult to establish accurate mathematics model according to the different dynamic model of every ship and dynamic disturbance. So, it is extremely difficult to tune the PID controller so as to procure a good behavior in all situations. Fuzzy control theory in the automatic marine steering is studied. It is the well-known fact that fuzzy logic systems need no accurate mathematical models of the system under control. They can approximate certain classes of functions to a given accuracy and furthermore the output of the system can be represented by fuzzy basis functions. Experts’ experience is essential when a ship is in course-keeping and course-changing manoeuvres. We design a fuzzy expert system that includes a knowledge base to store facts and rules, an inference engine to simulate experts’ decision and a fuzzy interface device. However, using the fuzzy logic and the traditional methods can not solve the contradictory problem. Extension logic, based on extension set of matter-element, is to research the contradictory problem. The combination of extenics and control theory brought a new type of intelligent control --- extension control into the world. The mathematics basis of traditional control, digital control, modern control, fuzzy control and neural network control is L transform, Z transform, status space analysis, fuzzy set and neural network topology respectively, while that of extension control is extension set theory. In 1983, Cei Wen proposed Extension Set Theory[1],In 1991, Li Jian and Wang Shienyu proposed a new concept of Extension Control[2], which basic idea is to solve control problem from the aspect of information transformation, in other word, to transform the control information into the eligible value range by using dependent degree to tune the output modification factors. In 1993, Li Jian and Wang Shienyu proposed a design method of extension controller[3], which built the canonical structure of extension controller and researched the realization methods of character models partition and dependent degree calculation, etc. In 1996, Pan Dong and Jin Yihui proposed dual-layer structure of control system[4], which includes upper-layer extension controller and basic extension controller. In 2000, Zhang Jiwen and Yu Yongquan improved and extended the former extension controller model and proposed the control algorithm of extension control based on matter-element model[5]. In the same year, Yang Lin, Wu Liming and Huang Aihua also proposed the matter element model and its algorithm of extension control[6]. In 2001, Chen Jenyang and Chen Jenyang proposed extension controller design based on sliding mode control[7]. By now, the extension theory and extension engineering method have been entering into many research fields of extension control[8-14].

Combination of the character of fuzzy and extension logic, this paper propose the fuzzy-extension control system for marine steering.

II. ESTABLSIH THE MODEL OF FUZZY-EXTENSION CONTROL SYSTEM

This paper proposes the fuzzy-extension control model. The control model is composed of fuzzy controller and extension controller, which are connected by a kind of intelligent control switch based on extension set. The output calculation of the fuzzy controller is based on the measure partition of extension set. It is built only upon the known classic field and limitation field and does not need provided mathematical models and provided control structure information. The extension controller is good at dealing with big change and qualitative change. It composed of extension mode, dependent degree calculation, extension analysis, extension transformation and excellent degree evaluation modules. The fuzzy-extension control system consists of fuzzy controller, extension controller, control transfer switch(CTS) and plant. The fuzzy-extension control system is shown as the figure 1. The structure of classical fuzzy controller is shown as figure2. And the structure of extension controller is shown as figure3.

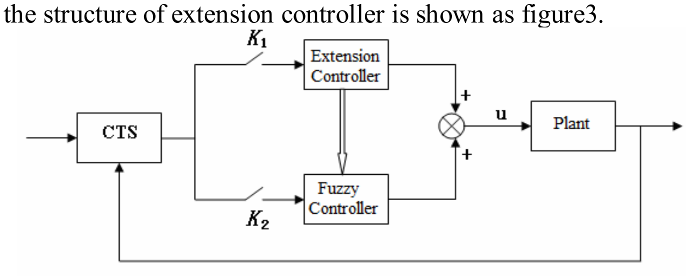

Figure 1 Fuzzy-Extension Control System

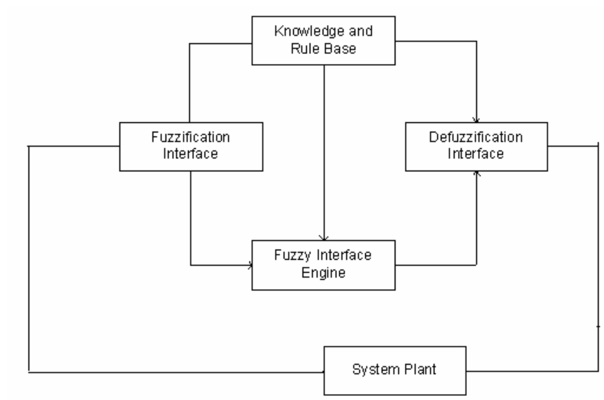

Figure 2 The structure of fuzzy controller

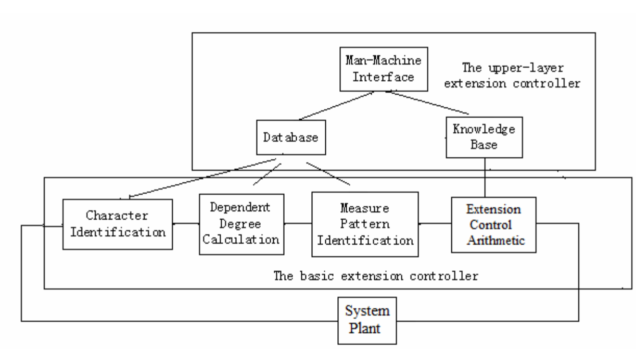

Figure 3 The structure of extension controller

Figure 3 shows the structure of extension controller, which adopts dual-lay structure including upper-layer extension controller and basic extension controller.

The upper layer extension controller consists of database, knowledge base and man-machine interface. Database and knowledge base are used for saving the information of control process and expert knowledge respectively. The basic extension controller consists of five parts: character identification, dependent degree calculation, measure pattern identification, extension control arithmetic. Character identification uses for extracting system characters from the current acquired system information and groups them into a certain character pattern. Dependent degree calculation is used for building the related extension set and dependent function by adopting current system status values so as to get the dependent degree of character status. Measure pattern identification groups the current characters into a certain pattern regulated by measure criterions. Extension control arithmetic uses for acquiring the output value of controller according to defined control patterns and related extension control algorithm.

III. FUZZY CONTROLLER DESIGN FOR MARINE STEERING

The fuzzy autopilot design is based on fuzzy inference mechanism. The memberships have been defined in the two inputs and one output fuzzy system. The inputs and outputs to the fuzzy controller are ① The yaw a error(ε) (reference ship course subtracted from actual course.) ② The yaw rate ($\dot{\alpha}$) (previous error subtracted from current error) over one sample period. ③ The output of the controller is the rudder angle (δ_C).

In practical applications, the control goals and system constraints are all of fuzzy characters, in order to unify them, fuzzy membership function is used to express their characters. These operators can be used to translate a linguistic description of control goals into a decision function. In this way, various forms of aggregation can be chosen giving greater flexibility for expressing the control goals. The universe of discourse (range) of the inputs and outputs are mapped into several fuzzy sets of desired shapes. The membership functions for the inputs are shown in Figure 4 and Figure 5, and outputs are shown in Figure 6.

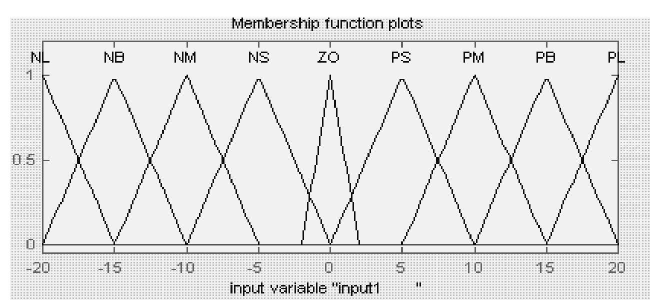

Figure 4 Membership functions for yaw error (ε)

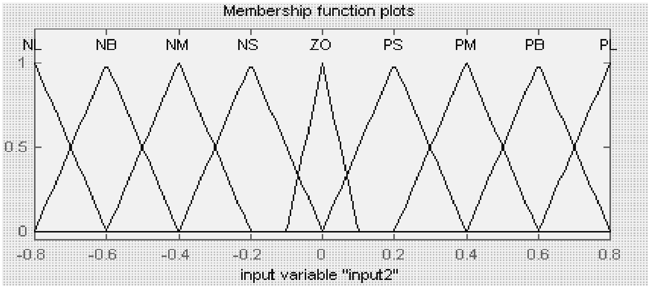

Figure 5 Membership functions for yaw rate (ω)

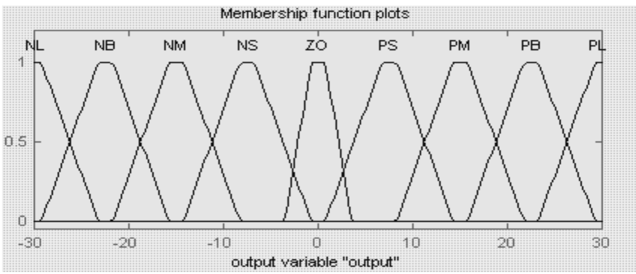

Figure 6 Membership functions for rudder angle (δ_c)

A fuzzy system is characterized by a set of linguistic statements based on expert knowledge. The expert knowledge is usually as "if-then" rules, which are easily implemented by fuzzy conditional statements in fuzzy logic. Fuzzy control rules have the form of fuzzy conditional statements that relate the state variables in the antecedent and process control variables in the consequence.

The initial rule base is given by the experience of expert. It captures much of the behavior of a skilled pilot or a helmsman. Rules that were developed in the work are given in Table1.

TABLE I. FUZZY RULES TABLE FOR MARINE STEERING

δ_c		ε								
		NL	NB	NM	NS	ZO	PS	PM	PB	PL
ϖ	NL	NL	NL	NL	NL	NL	NL	NB	NM	NS
	NB	NL	NL	NL	NL	NL	NB	NM	NS	ZO
	NM	NL	NL	NL	NL	NB	NM	NS	ZO	PS
	NS	NL	NL	NL	NB	NM	NS	ZO	PS	PM
	ZO	NL	NL	NB	NM	NS	ZO	PS	PM	PB
	PS	NL	NB	NM	NS	ZO	PS	PM	PL	PL
	PM	NB	NM	NS	ZO	PS	PM	PB	PL	PL
	PB	NM	NS	ZO	PS	PM	PB	PL	PL	PL
	PL	NS	ZO	PS	PM	PB	PL	PL	PL	PL

The original fuzzy controller designed for marine steering system is tested by simulation in Matlab using Simulink with Fuzzy Logic Toolbox.

IV. EXTENSION CONTROLLER DESIGN FOR MARINE STEERING

The extension controller adopts error e and error differential Δe as character values while the corresponding character status is $S = (e, \Delta e)$. In order to calculate the dependent degree $K_{\tilde{X}}(S)$, the corresponding extension set $\tilde{X}$ about character status S = (e, Δe) of basic extension controller must be built first.

Assumed that the allowable value ranges of error e and error differential Δe of control object are $[-e_{om}, e_{om}]$ and $[-\Delta e_{om}, \Delta e_{om}]$ respectively, the maximum extensible value range of error e and error differential Δe of control object are $[-e_m, e_m]$ and $[-\Delta e_m, \Delta e_m]$ respectively.

If measure pattern is *M1*, then not change the output of controller, remain the previous control value. Written as:

$$u(t) = u(t-1) \qquad (1)$$

If measure pattern is *M2,* then the output of controller is:

$$u(t) = y(t)/k + K_{ci}K(S)(-\operatorname{sgn}(e)) + \varepsilon \qquad (2)$$

where $u(t)$ is the current output value; $y(t)$ is the current sampling value of control object; k is the static gain; K_{ci} is the control parameter of the measure pattern *M2i*. S is the character status; $K(S)$ is the dependent degree of character status. $\operatorname{sgn}(e)$ is the symbol function of error e shown in the follows:

$$\operatorname{sgn}(e) = \begin{cases} 1, & e > 0 \\ 0, & e = 0 \\ -1, & e < 0 \end{cases} \qquad (3)$$

ε is a small modify value used for reducing interference and un-preciseness of process gain k . It is written as follows, where K_I, K_P is the suitable constants, δ is a small positive number.

$$\varepsilon = \begin{cases} K_I \int_0^t edt + K_p e & , |e| \le \delta \\ 0 & , \text{other} \end{cases} \qquad (4)$$

If measure pattern is *M3*, then the output of controller adopts maximum value. Written as

$$u(t) = u_m . \qquad (5)$$

From the above analysis, the whole algorithm of basic extension controller is as follows:

$$u(t) = \begin{cases} u(t-1), & K(s) \ge 0 \\ y(t)/k + K_{ci}K(s)(\text{-sgn}(e)) + \varepsilon, & -1 \le K(s) < 0 \\ u_m, & K(s) < -1 \end{cases} \qquad (6)$$

From the above error analysis, the output value $u(t)$ can be given as follows:

$$u(t) = y(t)/k - \operatorname{sgn}(e) \cdot K_{\tilde{X}}(S) \cdot u(t-1) \cdot p + \operatorname{sgn}(e) \cdot D_s \cdot g \qquad (7)$$

where $u(t)$ is the current output value; $y(t)$ is the current sampling value of control object; k is the static gain; $K_{\tilde{X}}(S)$ is the dependent degree of character status S; $u(t-1)$ is the last output value; D_s is the status distance. p and g are modification factors.

In this equation, dependent degree $K_{\tilde{X}}(S)$ and status distance D_s are adopted to modify the output value $u(t)$ .Sign(e) is the symbol function of error e shown in the follows:

$$\operatorname{sgn}(e)=\begin{cases}1, & e>0\\ 0, & e=0\\ -1, & e<0\end{cases} \tag{8}$$

So the whole extension control algorithm of basic extension controller based on dependent degree $K_{\tilde{X}}(S)$ and status distance D_s is as follows:

$$u(t)=\begin{cases}\text{adopts fuzzy control of classic domain}, & K(s)\geq 0\\ \dfrac{y(t)}{k}-\operatorname{sgn}(e)\cdot K(s)\cdot u(t-1)\cdot p+\operatorname{sgn}(e)\cdot M_s\cdot g & -1\leq K(s)<0\\ \text{exit control status and give warning signal} & K(s)<-1\end{cases} \tag{9}$$

In this paper, the control transfer switch(CTS) is designed by the dependent degree of character status $K_{\tilde{X}}(S)$.

$$K=\begin{cases}FuzzyControl, K(s)\geq 0\\ ExtensionControl, K(s)\in(-1,0)\end{cases} \tag{10}$$

Ⅴ. SIMULATION RESULT

An autopilot must fulfil two objectives: course-keeping and course-changing. In the first case, the control objective is to maintain the ship's heading following the desired course *(y(t)* =constant). In the second case, the aim is to implement the course change without oscillations and in the shortest time possible. In both situations, the operability of the system must be independent of the disturbances produced by the wind, the waves and the currents.

For course-changing and course-keeping of the marine steering, the performance of the fuzzy-extension controller designed is implemented in MATLAB/Simulink environment.

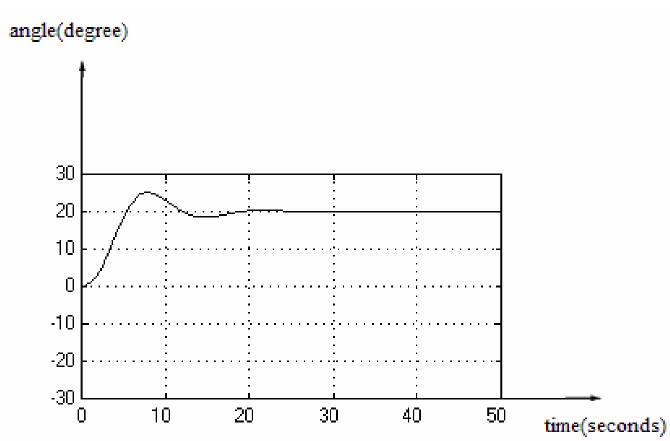

Figure 7 Course-changing steering: the heading response

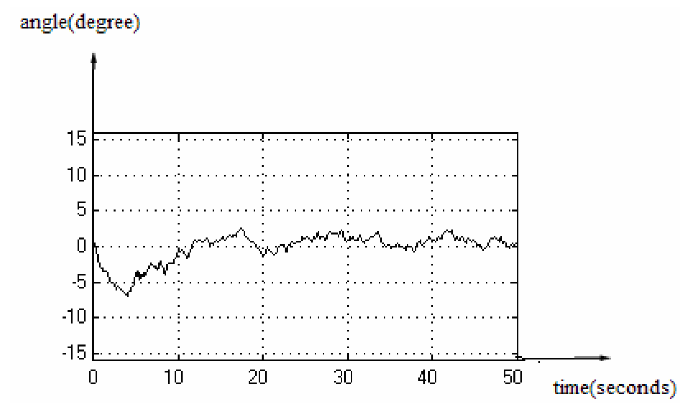

Figure 8 Course-keeping steering: the heading response with random disturbance

Figure 7 shows that the fuzzy-extensionn controller obtains satisfactory behavior for the course-changing steering. Figure 8 shows that the heading response of the designed controller under the random disturbance has good performance.

VI. CONCLUSION

This paper studied the design of an optimized fuzzy controller for the control of course-changing and course-keeping in marine steering. We presented a fusion method of extension sets and fuzzy sets and proposed the fuzzy-extension control system for marine steering. We studied the design of fuzzy-extension controller and obtained a satisfactory behavior in different manoeuvring situations.

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