International Journal of Control and Automation
Vol. 9, No. 8 (2016), pp.137-148
http//dx.doi.org/10.14257/ijca.2016.9.8.14

Research of Ship Motion based on Fuzzy Control

Xiong Ying and Hu Jun Jie
South-Central University for Nationalities, Wuhan 430074, China
304074461@qq.com

Abstract

In this thesis we build the parametric mathematical model of machine tool and solid models of traction gears using in subway locomotive by analyzing the machining process of involute gears and meshing principle of involute gears. The optimization design is done through deduce the relations between basic parameters of gear and loading capacity of transmission. On the base of analyzing optimization principles and methods for involute gear system the software is obtained by considering the contact fatigue strength of teeth surface, the bending fatigue strength of root fillet and scuffing strength of teeth surface. It is optimized that the best parameters decide the strength safety and loading capacity by analyzing the optimization results.

Keywords*: ship motion, course control, fuzzy control*

1. Introduction

The ship motion [1-5]has the characteristics of nonlinear and its dynamic characteristics are closely related to the operating conditions (ship type, loading, speed, draft, *etc*.) In PID steering apparatus, It is usually take the control parameters are neatly on the way to adapt to changes in the sailing ship conditions and external environment. But if the control parameters are not appropriate, it will make the control effect becomes worse, steering greatly and frequently, steering gear lose a lot, and lacking of the adaptive ability of ship dynamic and sea change. Adaptive autopilot Improve the accuracy of control and Reduce the amount of control effort, but It's based on the parameter estimation of the cost function. And it needs to build the model of the disturbance. The algorithm is complicated, it's high cost too. And the characteristics of ship is nonlinear, The control effect and stability is difficult to guarantee. Fuzzy control is a mathematical model that based on the artificial experience without knowing the exact control object. it has the characteristics of non sensitivity and robustness to parameter variations. But the control precision is not ideal. If the fuzzy integral link is added to the fuzzy controller. It can better adapt to the changes of the parameters of the ship course control system and the changes of the external environment, and can improve the control precision of the course.

2. Fuzzy Controller for Ship Course Motion

Considering the fuzzy controller's simplicity and rapidity for achieving it, the shipping course's fuzzy controller usually adopts the two-dimensional fuzzy controller structure in a typical fuzzy control system [6-11]the Two-dimensional fuzzy controller basically choose controlled variation. the errors from inputting and changing factor as the inputting variations, as they can strictly reflect the dynamic characteristics of outputting variations in the process of controlling, hence, they are widely used because It's more easy to control and complete it. Two-dimensional fuzzy controller's effects are similar to the conventional PD (proportional differential) controller's, contrary to which static performance, the fuzzy controller system is able to obtain good dynamic characteristics. According to the linear control theory, although the integral control actions can eliminate

ISSN: 2005-4297 IJCA

the steady-state errors, its dynamic response is slower, the proportional control actions possess fast dynamic responses, moreover, the proportional integral control actions not only can obtain higher steady-state accuracy, but also has higher dynamic response .therefore, it is a realizable way to improve the steady state performance if we combine the PI control strategy with Fuzzy controller, then form a Fuzzy control model with Fuzzy integral segments .

In conclusion, what we need to do for a satisfactory controlling performance is to apply Fuzzy controller with fuzzy integral segments that can be used to control the shipping course motion to the shipping course motion control system.

2.1. The Design of Anti Disturbance Tracking Differentiator

The design of anti disturbance tracking differentiator is that the course deviation or the filter after the heading error will be input as a two-dimensional fuzzy controller in ship course motion fuzzy control system, but due to the course deviation or the filter after the course deviation, it is easily to introduce high frequency interference in solving the rate of course deviation, which makes the rate of course deviation change vulnerable to the high frequency noise pollution. The premise of fuzzy controller design is to how to utilize the heading error or the filtered heading error signal to solve the variation rate of the heading error.

Learning from the anti disturbance control theory [12-13]，the change rate of course deviation can be solved by using the most speed discrete time tracking differentiator. Course deviation steepest discrete-time tracking differentiator can be briefly described as following:

Provided that the ship moves at low speed that is changed 1 Eve joy, the transition time T, the provisions of the ship changed to time scale“r=1/T” . In the process of the course change, the reference trajectory:

$$\begin{cases} w(0) = \psi_z - \psi(0) \\ w(k+1) = \gamma w(k) \end{cases} \tag{1}$$

Remember to:

$$fsg(x,d) = (sign(x+d) - sign(x-d))/2 \tag{2}$$

Is there:

$$\begin{cases} d = rh^2 \\ a_0 = hx_2 \\ y = x_1 + a_0 \\ a_1 = \sqrt{d(d+8|y|)} \\ a_2 = a_0 + sign(y)(a_1 - d)/2 \\ a = (a_0 + y)\, fsg(y,d) + a_2(1 - fsg(y,d)) \\ fhan = -r(\frac{a}{d})\, fsg(a,d) - rsign(a)(1 - fsg(a,d)) \end{cases} \tag{3}$$

The discrete tracking value of the variation of the heading error rate is as follows:

$$\begin{cases} fh = fhan(\psi(k) - w(k), x_2(k), r, h) \\ x_1(k+1) = x_1(k) + hx_2(k) \\ x_2(k+1) = x_2(k) + hfh \end{cases} \tag{4}$$

In style,x2 (k+1)is the change rate of course deviation.

If the value of deviation rate tracking course to solve noise is bigger, in the style fhan(x1,x2,r,h) the variable h can be changed to and step h independent new variables h0 take to the appropriate parameters of step h length is greater than it can eliminate noise amplification effect.

2.2. The Design of Fuzzy Controller

Using the immunity of steepest discrete time tracking differentiator and deviation rate of ship course tracking values, values of the track and heading error or filter after heading error as input variable of fuzzy controller, build a two-dimensional fuzzy, to eliminate the steady-state error. The integral separation principle can be in fuzzy integral part of ship course control system developed for the changes to a certain range.

In order to establish the fuzzy two-dimensional fuzzy controller, the first input variables must be ship course deviation e and deviation rate ec , output variables delta,namely, to establish the fuzzy. Then based on the experience of experts or ship maneuvering of the ship course motion control operating system generated by observation and measurement control rules, establishing the fuzzy rule base, using fuzzy inference machine to logical reasoning, and then get the output variables of fuzzy output; At last, using the right solution to the fuzzy judgment method to establish, and getting the output variable instruction clear solution of rudder Angle delta as a result.

2.2.1. Blur

Fuzzy processing is in the fuzzy controller, when the ship is doing curse movement. The following are the specific processes:

First, regard the course deviation e and the changeable rate ec of deviation as the input, the rudder Angle indicator suggests as the output. Then consider the input and output as the fuzzy controller's input and output language variables quantity.

Second, according to the experience of sailing, ensure the input's e discourse dominion as [-30°,30°];ec's discourse domain as[-1°/s,1°/s] , the discourse dominion of the rudder angle which the output suggests as [-30°,30°] .

Third, fuzzy processing the input and output which have already been in the reach of the discourse domain, making accurate input and output become blurry and indicating it by using the corresponding fuzzy set.

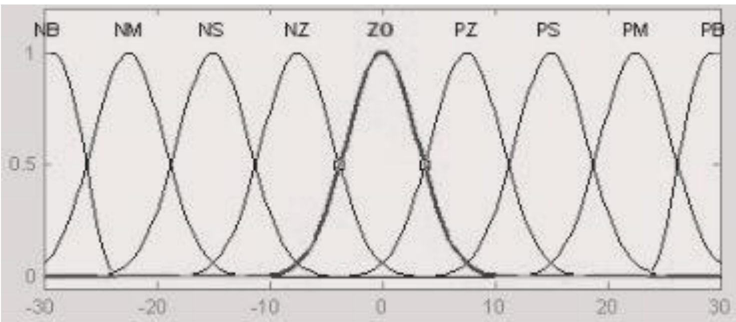


Figure 1. Input e's Membership Function Curve

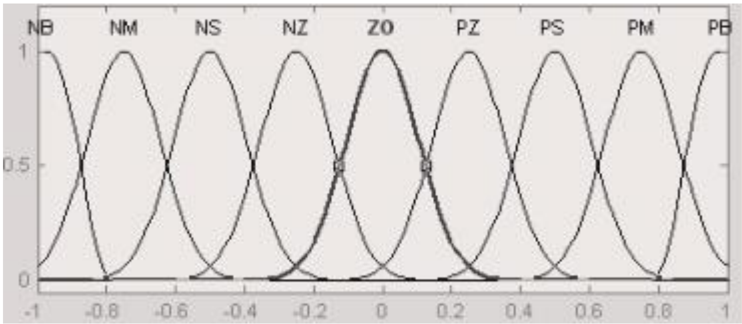


Figure 2. Input ec's Membership Function Curve

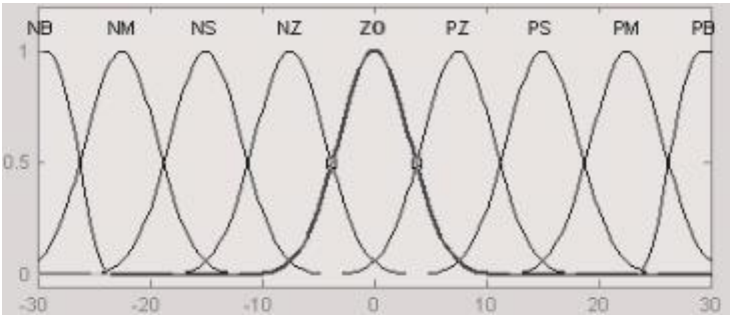


Figure 3. Output Delta's Membership Function Curve

In the Fuzzy Control of Ship Course Motion, the values of linguistic variables are shown as nine degrees, including 'Negative Big' (NB),'Negative Medium' (NM),'Negative Small' (NS) ,'Negative Zero' (NZ),'Zero'(ZO),'Positive Zero'(PZ),'Positive Small' (PS),'Positive Medium' (PM) and 'Positive Big' (PB).Among them, the 'Negative Big' (NB) Membership Function adopts the Z-shaped ones, 'Positive Big' (PB) adopts S-shaped ones, and the rest adopt Gaussian ones.The shapes of the Membership Functions have much influence on the Control Effects. Wide-type membership Function reflects some features, which includes the low resolution of fuzzy set, low sensitivity of error control, as well as gentle-control characteristics. Therefore, we choose the wider ones. There are some overlaps between the adjacent two Membership Functions, but no cross-border in the intervals.Picture1 to picture 3 are related to Membership Functions Curves for references.

2.2.2. Knowledge Base

Fuzzy Rule, Base, containing the knowledge of Ship Course Motion Control and the Control Objective of its requirements, is a series of the "IF-THEN" type of fuzzy conditional sentences--the antecedent of a conditional sentence is for inputting and stating, the parts after a conditional sentence parts are as control variables.

Rule Base contains a series of control rules expressed with Fuzzy Linguistic Variables, which reflect the experience and knowledge of Control Specialists. Also, Experimental Rules can be conducted by the Typical step response of the ship course motion control process.

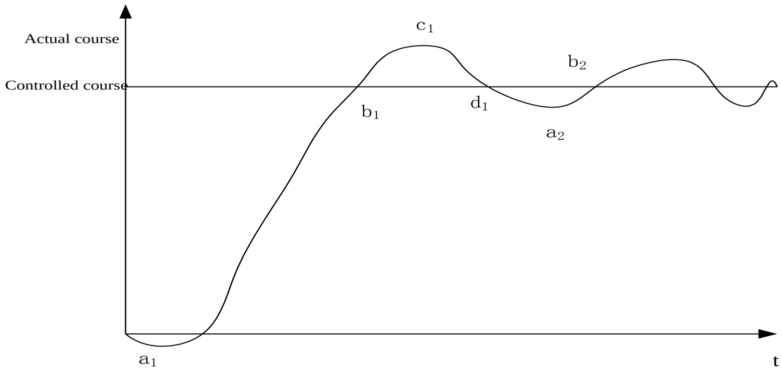


Figure 4. Typical Step Response of Ship Course Control

Table 1. Control Rule Table

e	ec								
	NB	NM	NS	NZ	ZO	PZ	PS	PM	PB
NB	NB	NB	NM	NM	NS	NS	NZ	NZ	ZO
NM	NB	NM	NM	NS	NS	NZ	NZ	ZO	PZ
NS	NM	NM	NS	NS	NZ	NZ	ZO	PZ	PZ
NZ	NM	NS	NS	NZ	NZ	ZO	PZ	PZ	PS
ZO	NS	NS	NZ	NZ	ZO	PZ	PZ	PS	PS
PZ	NS	NZ	NZ	ZO	PZ	PZ	PS	PS	PM
PS	NZ	NZ	ZO	PZ	PZ	PS	PS	PM	PM
PM	NZ	ZO	PZ	PZ	PS	PS	PM	PM	PB
PB	ZO	PZ	PZ	PS	PS	PM	PM	PB	PB

Figure 4 describes the typical step response of ship course motion control process, at the beginning, namely near a1, need a slightly larger rudder angle signal rapidly make the ship turn rapidly . In the near a1 rules as follows:

If e is PB and ec is ZO and then delta is PS.

Near b1 in Figure 4, need a small controlling signal in order to avoid the actual course of overshoot is too big, therefore, need to adopt the following rules:

If e is ZO and ec is NB and then delta is NS.

Near the point c1 and d1 the controlling behavior is similar to point near the a1 and b1, respectively.

Using such ideas can be concluded that the fuzzy controller according to e and ec and the instruction of the rudder angle for online adjustment rules: when |e| is larger, should take larger rudder angle. When |e| is in middle size, in order to prevent larger overshoot, rudder angle should be adequately smaller. When |e| is smaller , ec should hold more small rudder angle. When the absolute value of is small the instruct rudder angle should take smaller hours .

Performance requirements of the fuzzy control rules: firstly, it is completeness, namely for any input shall ensure that it has at least one optional rules, and the rules of the applicable degree should be bigger than a certain value; Second, on the premise of completeness, make the rules for less as far as possible, in order to simplify the fuzzy controller's design and implementation; Thirdly, the case that it has contradictory between fuzzy control rules can't happen.

According to the control principles of fuzzy controller and performance requirements of fuzzy control rules , therefore,e,ec, and delta 's setting rules of the fuzzy control shown in Table1.

2.2.3. The Fuzzy Reasoning

Fuzzy inference machine is the core of the fuzzy control system, based on the concept of fuzzy. Fuzzy control information can be through fuzzy implication and the fuzzy logic inference rules to obtain. And it can also realize the process of the personifying decision-making .According to the fuzzy inputs and fuzzy control rules, fuzzy inference machine can solve the fuzzy relation equations and obtain the fuzzy outputs.

Product inference machine, Minimum inference machine, Zadeh inference machine, LukasiseWicz inference machine and Dienes - Rescher inference machine are mainly used in control system. In this paper,in the fuzzy self-tuning PID control system of ship course, product inference machine is adopted.

2.2.4. The Blur

What obtained by fuzzy reasoning is fuzzy quantity, and for the actual control must be non fuzzy quantity that is clarity, so it is needed to convert the fuzzy quantity into clarity, and the representation of the clarity that in the theory of domain is transformed into the actual control quantity by scale transformation. There are usually several methods to transform fuzzy control into the clarity that expressed in the theory of domain by the clear calculation, such as, maximum membership degree method, median judgment method and the area center method.

The above three methods have advantages and disadvantages of each. Maximum membership degree method is simple, easy to use, good real-time, but with little information; Median judgment method uses too much information, with large amount of calculation. Area center method not only has the formula to follow, the use of information is more and the practical application is more extensive, so this thesis uses it to carry on fuzzy decision-making.

2.3. Design of Fuzzy Integral

Fuzzy integral part adopts two input and single output in the form of two-dimensional fuzzy controller. Using the integral separation principle, at the time |e|≤5°,again join integral part of the controller's output signal, in order to eliminate the steady-state error. Fuzzy integral link e and∑e as input language variable, with small rudder Angle as the language of the output variable the theory of domain for [-5°,5°], the theory of domain for [-10°,10°], the theory delta1's domain for [-3°,3°]. Input and output variables of language values are shown as "negative" (NB), "negative" (NS), "zero" (ZO), was "small" (PS) and "board" (PB) five kinds. Among them, the "negative" (NBZ) use "Z" shaped membership functions, "the board" (PB) with "S" shape of membership functions, the rest of the membership function by Gauss membership function. Input language variable and output variable of the membership function curve as shown in Figure 5 ~ Figure 7.

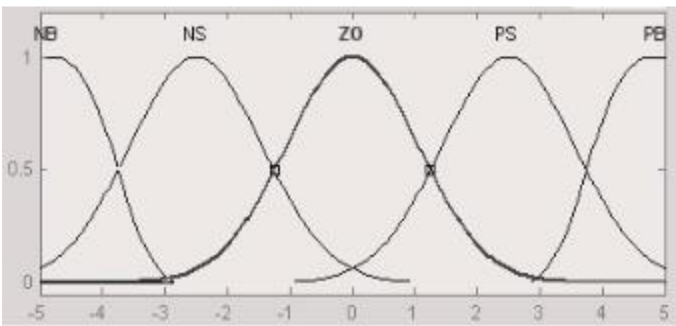


Figure 5. Input e's Membership Function Curve

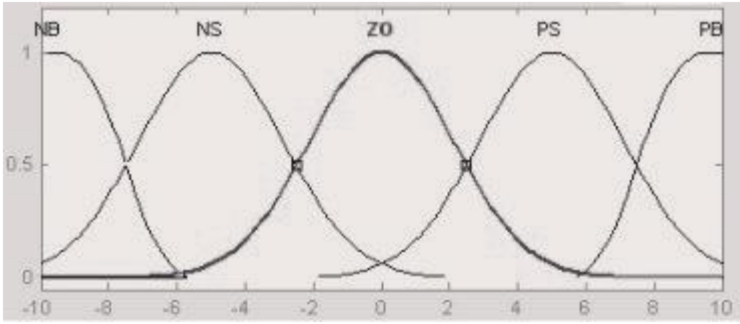


Figure 6. Input ∑e's Membership Function Curve

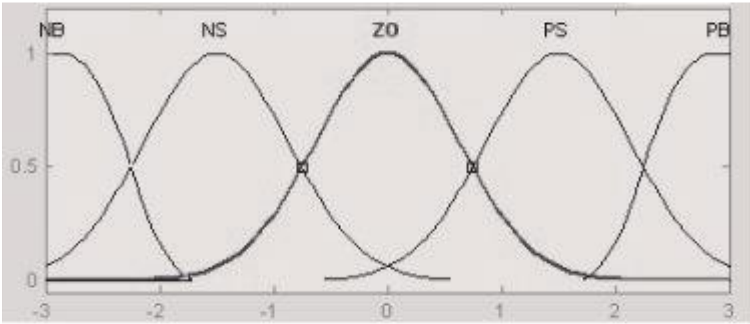


Figure 7. Output Delta's Membership Function Curve

Fuzzy integral link control rules Table such as Table 2. Using product inference engine of fuzzy reasoning, fuzzy device adopts fuzzy average solution center.

Table 2. Delta1's Control Rule Table

e	∑e				
	NB	NS	ZO	PS	PB
NB	NB	NB	NS	NS	ZO
NS	NB	NS	NS	ZO	PS
ZO	NS	NS	ZO	PS	PS
PS	NS	ZO	PS	PS	PB
PB	ZO	PS	PS	PB	PB

3. System Simulation and Verification

System simulation gets the curved surface of output lingual variable and the output characteristic of fuzzy reasoning as shown in Figure 8 and Figure 9 by using MATLAB/fuzzy toolbox for ship course's fuzzy controller and fuzzy integral link with graphics editor interface.

Figure 8 and 9 show that the curved of two-dimensional fuzzy controller and fuzzy reasoning output characteristic of fuzzy integral part are over-smoothing and without mutations. Therefore, the control system can carry out simulation with the reasonable choice of fuzzy control regulation.

In order to verify the effect of the ship course's fuzzy controller, the ship course motion with speed of six, ten and fifteen knots is simulated in infinite deep, wide and static area, meanwhile, the simulation of general PID control in corresponding speed is carried out. There is a set of optimal PID controller parameters under different speed in Table 3 and the PID controller adopt integral separation principle and at that time showing in that picture, cancelintegral link$|e|>5°$.

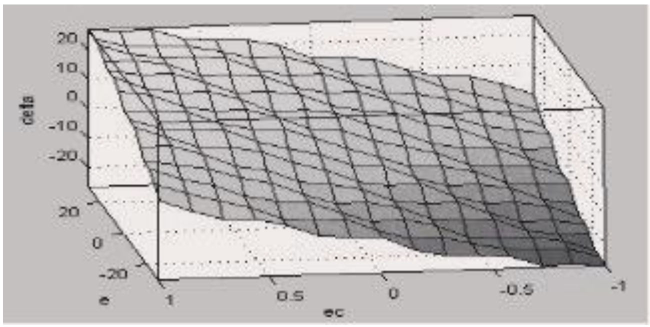


Figure 8. Fuzzy Reasoning Output Characteristic Surface of Two Dimensional Fuzzy Controller

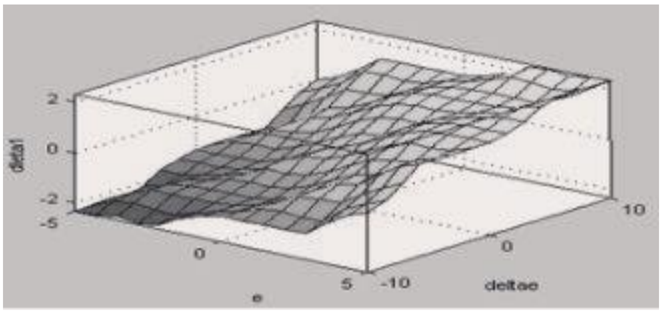
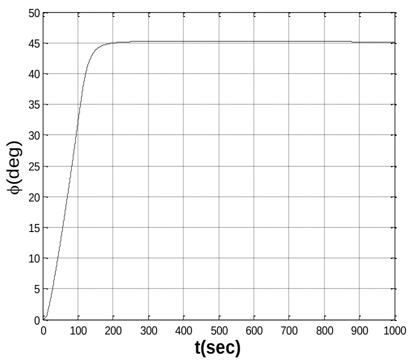


Figure 9. Output Characteristic Surface of Fuzzy Integral Link

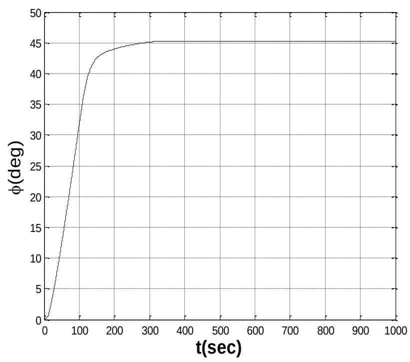
Table 3. Parameter List of Conventional PID Controller

PID / Speed(kn)	K_p	K_d	K_i
6	3.5	35	1/80
10	2.8	28	1/65
15	2.5	22	1/60

(1)the speed of forty-five knots, heading change six degrees PID control and fuzzy control contrast curve

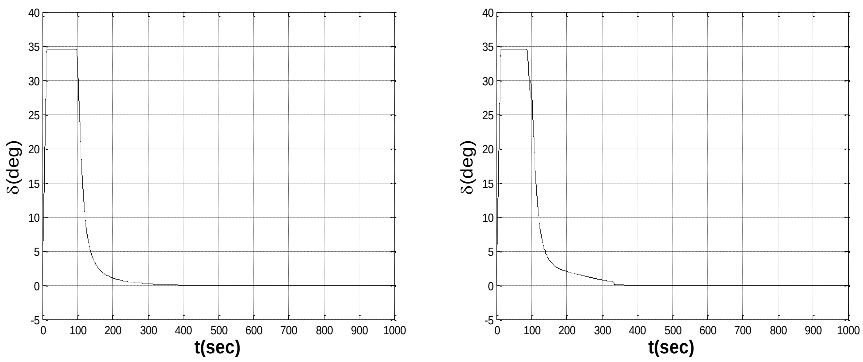


PID control course response curve



Fuzzy control course response curve

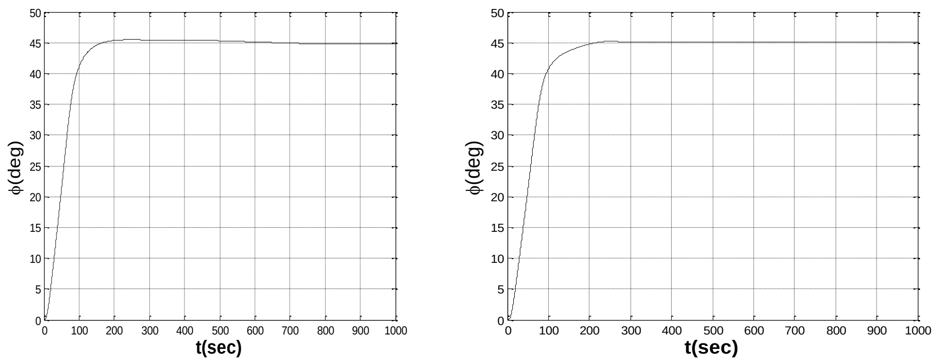
Figure 10. Course Response Curve Comparison Chart



PID control rudder angle curve Fuzzy control rudder angle curve

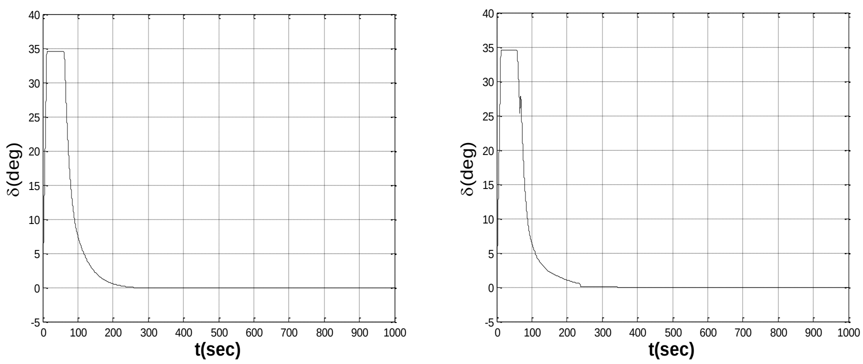
Figure 11. Comparison Chart of Rudder Angle Change Curve

(2)the speed of forty-five knots, heading change ten degrees PID control and fuzzy control contrast curve



PID control course response curve Fuzzy control course response curve

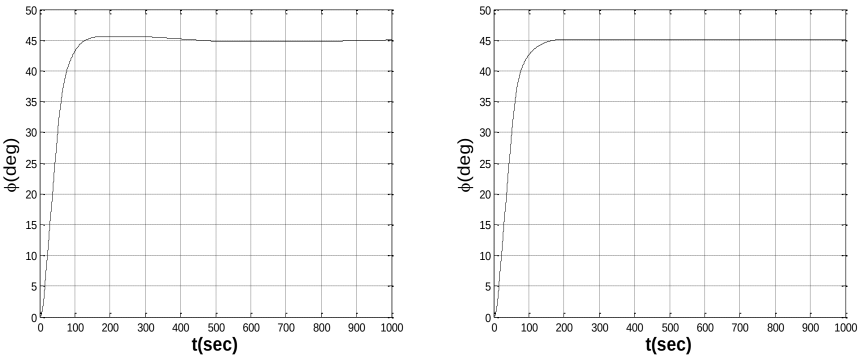
Figure 12. Course Response Curve Comparison Chart



PID control rudder angle curve Fuzzy control rudder angle curve

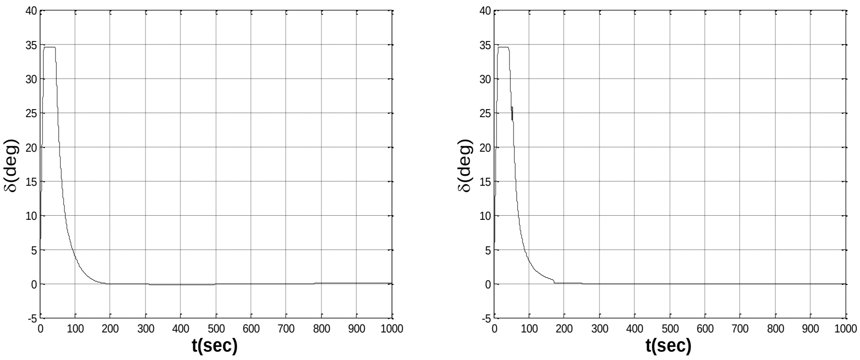
Figure 13. Comparison Chart of Rudder Angle Change Curve

(3)the speed of forty-five knots, heading change fifteen degrees PID control and fuzzy control contrast curve



PID control course response curve Fuzzy control course response curve

Figure 14. Course Response Curve Comparison Chart



PID control rudder angle curve Fuzzy control rudder angle curve

Figure 15. Comparison Chart of Rudder Angle Change Curve

4. Conclusions

As can be seen from the Figure 10 ~ 15, when using the PID controller to control the ship course motion, through under different speed adjust PID controller parameters can be abstained very good control effect, under different speed of ship course motion response of smooth transition process, there is no overshoot, so people tooling controller parameters to realize ship course's control. But in order to obtain ideal control effect, the parameters of PID controller must be conducted according to the variation of speed setting, lack of adaptability. When using fuzzy controller to control the ship course motion, can get ideal control effect and strong adaptability.

The simulation analysis shows that the fuzzy controller to control the ship course motion can obtain better control effect. Thus can think that the ship course's fuzzy controller is proposed in this paper has stronger adaptability and better robustness.

Acknowledgments

(1) Foundation of the Fundamental Research Funds for the Central Universities, South-Central University for Nationalities (CZY14002)

(2) Foundation of Hubei Key Laboratory of Intelligent Wireless Communications, South-Central University for Nationalities, China

References

[1] Anon, "Wonderware and Woodhead strengthen connectivity with Archestr", A technology. Paper Industry, vol. 21, Issue 6, **(2004)**, pp. 15-17.
[2] W.-S. Fang, W. Li, J.-B. Cai, "The generalization of integrated platform management system's development for foreign naval ships", Ship Science and Technology, vol.27, Issue 1, **(2005)**, pp. 94-96.
[3] J.-H. Lin and S.-T. Chen, "Integrated platform management system for ships based on Industrial Ethernet", JIANGSU SHIP, vol. 29, Issue 2, **(2012)**, pp. 31-35.
[4] Y.-Q. Ren and H. Xu, "Development of integrated platform management system", Ship Science and Technology, vol.27, Issue 6, **(2005)**, pp. 105-108.
[5] Q. Han and R.-Q. Mao, "Network pattern of naval ship synthesized platform management", SHIP & BOAT, vol. 8, Issue 4, **(2004)**, pp. 56-58.
[6] Y. Ye and J.-H. Li, "Research of integrated platform management system for ships", China Water Transport, vol. 4, Issue 11, **(2006)**, pp. 15-16.
[7] L.-S. Huang and Y.-B. Sun, "Architecture of Warship Integrated Platform Management System", Ship Electronic Engineering, vol. 24, Issue 6, **(2004)**, pp. 50-54.
[8] S. Wei, Y. Xiong and P. Hu, "Establishment of Universal Model of Ship Integrated Platform Management System", Chinese Journal of Ship Research, vol. 3, Issue 5, **(2008)**, pp. 57-61.
[9] F. A. Papoulias and B. D. Mckinley, "Inverted Pendulum Stabilization of Submarines in Free Positive Buoyancy Ascent", J.S.R, vol. 38, Issue 1,**(1994)**, pp. 71-82.
[10] R. J. Richards and C. P. Stoten, "Depth Control of a Submersible Vehicles", I.S.P, vol. 28, Issue 318, **(1981)**, pp. 30-39.
[11] G. F. Gueler, "Modelling Design and Analysis of an Autopilot for Submarine vehicles", I.S.P, 1989, Budynas, Nisbett Shigley. Mechanical Engineering. America, McGraw-Hill Companies, vol. 36, Issue 405, **(1989)**, pp. 51-58.

Authors

Xiong Ying, He received Ph. D degree in 2011. His research interests include Intelligent Control, Cloud Computing.Working Place: School of Electronic Information Engineering, South-Central University for Nationalities.