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Fuzzy Control in Compensation System of Deep Mine Mining Pipeline Heave Compensation

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Abstract: The hydraulic lifting type deep-sea multi-metal manganese nodules mining technology is widely used in deep-sea mining as a cutting-edge technology. In the mining process, due to the influence of ocean wind, waves, current and tide, the mining ship is inevitably in the direction of gravity. A significant heave movement occurs on the top. In order to improve the stability, reliability and service life of the mining pipe and the working efficiency and economy of the entire mining system. A set of lift pipe compensation system should be installed between the upper part of the pipe and the mining ship. Based on the above background, the purpose of this paper is to study the application of fuzzy control in the deep sea mining pipe heave compensation system. In this paper, the idea of fuzzy control is proposed for the time-varying, nonlinear and mathematical models of hydraulic system. The system adopts three main control strategies, namely fuzzy control, fuzzy self-tuning PID control and fuzzy PID composite control. The results show that the classical PID control displacement is between -4.5 and 4.5 mm, while the fuzzy self-tuning PID control displacement is between -4.2 and 2.2 mm, which improves the accuracy of PID control. It can be seen in the fuzzy control with different discrete levels that the large discrete level fuzzy control is obviously higher than the precision of the small discrete level control. It can reach -1.7 to 0.5 mm, greatly improving its accuracy. They are both robust to classical PID control and show good results in control. Among them, fuzzy PID composite control is more superior and practical.

1. Introduction

With the development of global industry, the shortage of land resources has become increasingly serious, and the world has begun to look at the development of resources to the sea [1]. The deep sea is the last unexplored area on the planet, and its rich mineral resources have become the focus of attention around the world. Deep sea mining has also become a subject of worldwide research. The 21st century has become the "Ocean Century", a new century in which humans recognize, develop, utilize, and protect the ocean [2]. The ocean accounts for 2/3 of the earth's area. The ocean is the cradle of life and a treasure house of resources. In the process of human society development, the ocean plays an increasingly important role. As the world's population continues to grow, land resources are diminishing, and human beings are not turning their attention to the ocean. The international seabed outside the jurisdiction of countries is rich in mineral resources of ocean polymetallic nodules. Therefore, marching into the deep sea and developing large-scale mineral resources has become a strategic goal of all countries in the world [3-4]. The oceans occupies a large amount of resources. If they are properly developed and utilized, they will meet the needs of mankind within a few hundred years. The rapidly growing population will accelerate the consumption of terrestrial resources. The ocean has a large amount of mineral resources, but due to technical limitations the development is rare. The resources that have been identified are as many as 600 billion tons. They are scattered on the seabed. Marine minerals can be roughly classified into the following categories: water-soluble elements such as salt, magnesium, bromine, potassium carbonate, boron, gold, silver, uranium, etc. [5-6]. The shallow sea marine ore mining is the most convenient, containing a large amount of gold and more valuable than gold diamond, quartz, diamond, monazite, ilmenite, xenotime, rutile, magnetite and so on. The continental shelf deposits minerals such as phosphate rock, glauconite, barite, and silica [7]. The deep sea stores polymetallic nodules including nickel, cobalt, copper, magnesium, zirconium, iron, lead, zinc, and polymetallic sulfides include iron, zinc, copper, and the like. Manganese nodules with polymetallic nodules are among the most economical ones [8]. Polymetallic manganese nodules are rich in iron, manganese, nickel and copper. The chemical composition of the cobalt-rich manganese crust is basically the same as that of manganese nodules, but its cobalt content is relatively high, which can be used as an ore resource for extracting metals and an oxidation catalyst for purifying air. Storage under the ocean surface includes resources such as oil, coal, natural gas, sulfur, and ore [9-10].

In the most promising fluid pipeline lifting system, the mining pipe is an indispensable component [11]. The mining pipe is suspended at the lower end of the mining vessel and penetrates to the bottom of the sea for about 5,000 meters. It is subjected to the hydrodynamic force generated by currents and waves. Due to the influence of ocean wind, waves, currents and tides, it is inevitable for the mining ship to produce significant heave motion in the direction of gravity [12]. If there is a rigid connection between the lifting pipe and the mining vessel, without any compensating device, under the influence of external load and under the influence of the weight of the pipe and the buffer, the pipe will produce tensile and bending deformation and corresponding axial tensile stress. And the bending stress, the deformation of the pipe and the magnitude of the stress directly affect the stability, reliability and service life of the pipe and the working efficiency and economy of the entire mining system [13]. To this end, a set of lifting pipe heave compensation system should be installed between the upper part of the pipe and the mining ship to keep the deep sea mining operation normal [14]. The purpose of installing the lift pipe compensation system is to keep the mining pipe as static as possible when the mining ship rises with the wave, reduce or even eliminate the longitudinal vibration of the pipe, and make the pipe change. The axial stress and axial deformation are as small as possible to ensure the stability of the working of the mining system and improve the reliability and economy of the mining system [15].

The experimental system of this paper is mainly composed of industrial computer, proportional valve, grating displacement sensor, data acquisition card and D/A card. They are the hardware foundation of the system. In this paper, the idea of fuzzy control is proposed for the time-varying, nonlinear and mathematical model of hydraulic system. The system adopts three main control strategies, namely fuzzy control, fuzzy self-tuning PID control and fuzzy PID composite control. And experimental results show that they are both robust to classical PID control. It shows good results in the control. Among them, fuzzy PID composite control is more superior and practical.

The first chapter mainly describes the background, significance and research status of the topic, summarizes the development of intelligent control, the development of deep sea mining and the application of fuzzy control in deep sea mining technology, and puts forward the research content of this paper. The second chapter puts forward the hardware of the heave compensation simulation system, and designs the components such as industrial computer, grating displacement sensor, D/A card, proportional controller and proportional directional valve. The third chapter is a brief introduction to the background, methods and steps of this experimental study. The fourth chapter makes an in-depth study on the fuzzy control strategy of the heave compensation simulation system. The heave compensation system is a nonlinear time-varying hydraulic system. Therefore, the control strategy of the heave compensation system is required to have strong robustness and self-learning ability under complex sea conditions of variable load, variable amplitude and variable frequency. For the two kinds of heave compensation systems of light load and heavy load, three control strategies of fuzzy control, fuzzy PID composite control and fuzzy self-tuning PID control are proposed. The fifth chapter analyzes and summarizes. This chapter mainly analyzes and summarizes the experiments. On the basis of careful summarization and summary of the research, this paper points out the gains and losses of this research.

2. Proposed Method

2.1. Related Work

In this study, Huang proposed a simplified mechanical semi-active heave compensation system. The system consists of an active compensation section, a pinion and a rack, and a passive compensation section. To evaluate the system performance of the MSAHC, they built their simulation models using AMEsim software. During the simulation, the displacement and energy consumption of the rotating hook are considered to be the performance parameters of the system. The variation of the two performance parameters is analyzed by changing these design parameters. Then, based on the simulation results of the MSAHC system performance, they chose a set of optimal design parameters. Moreover, by comparing with the existing three-sink compensation system, the feasibility of the MSAHC design scheme is effectively verified. The results show that while achieving the same compensation effect, the MSAHC consumes less energy than the active heave compensation system and the semi-active heave compensation system, and the MSAHC accumulator is only half the volume. As a result, the newly designed MSAHC not only ensures compensation, but also reduces energy consumption and simplifies its construction by using a simple mechanical structure, thereby reducing manufacturing costs, maintenance costs and floor space [16].

In order to reduce the energy consumption of the electric winch compensation system for offshore drilling, the decoupling control of the heave compensation motion and the automatic feed motion is realized, and the energy saving method and control strategy of the compensation winch are studied. Based on the heavy-duty characteristics of the system, based on the hybrid and hydraulic energy recovery, Quan proposed a new hydraulic winch compensation system. The passive hydraulic motor can withstand part of the drill string static load, and the hydraulic auxiliary adjustment component uses the hydraulic accumulator to achieve periodic recovery and reuse of the system potential energy and kinetic energy. Quan proposed a software decoupling control strategy based on double closed loop control of heave and bit feed. The displacement and cascade control structure of the hydraulic winch compensation system finally established the simulation model of the compensation system, and developed the prototype of the compensation winch. The simulation and experimental results show that the decoupling control effect of the hydraulic winch compensation system is better than that of the electric winch, and the energy saving effect is remarkable [17].

In order to compensate for the heave movement of the ship crane during offshore operations, Wang constructed the hydraulic drive system of the crane based on the secondary adjustment hydrostatic drive technology. First, a complete mathematical model of the heave compensation system is proposed. The triple closed-loop control structure proposes a closed loop of the position of the stroke cylinder fixed in the secondary unit, a closed loop of the secondary adjustment hydraulic motor and a closed loop of the position of the secondary adjustment hydraulic motor. Then, a simple design approach proposes a method for determining the parameters of the three controllers. In order to obtain the position of the crane cargo, an observer was designed to estimate the state using the tension of the wire rope. Finally, a design example of active heave compensation is provided. The numerical simulation of the dynamic characteristics of the heave compensation system in the frequency domain is helpful to lay the foundation of the control strategy research [18]. Intelligent structures include elements of active, passive or hybrid control. Marinaki believed that fuzzy control is a suitable tool for systems to develop active control strategies. Marinaki proposed and tested a new multi-objective differential evolution algorithm for computing free parameters in active control systems. In particular, the use of MODE combining continuous variables and discrete variables has been proposed to achieve optimal design of the controller. The numerical application of intelligent piezoelectric elastic beam is introduced. The results obtained are compared with those obtained by the fuzzy controller optimized by the MOPSO algorithm [19]. Fuchun studied a kind of compound fuzzy control based on disturbance observer for an uncertain nonlinear system with unknown dead zone. Constructing compound learning based on serial parallel identifiers by approximating unknown nonlinearities through fuzzy logic systems. By introducing intermediate signals, an interference observer can be developed to provide efficient learning of complex interference, including time-varying interference, fuzzy approximation errors, and effects of unknown dead zones. Based on the disturbance estimation and fuzzy approximation, the adaptive fuzzy controller is synthesized by a novel update law. The stability analysis of the closed-loop system is strictly established by the Lyapunov method. The performance of the proposed controller is verified by simulation, and faster convergence and higher precision are obtained [20].

2.2. Application of Fuzzy Control in Heave Compensation System

Fuzzy control is widely used because it does not need to establish a mathematical model of the object. However, there are also shortcomings such as easy oscillation and poor stability. It is impossible to achieve ideal results by simply relying on PID control or fuzzy control. It can be combined with PID control to develop strengths and avoid weaknesses.

2.2.1. Current Status of Fuzzy Control Theory

The development of fuzzy control theory is mainly the fusion of fuzzy control and neural network. It can train fuzzy rules through the learning ability of neural network and improve the adaptive ability of the whole system. The combination of fuzzy control and genetic algorithm can realize optimal learning for controlled objects. Expert fuzzy control can improve the intelligent level of fuzzy control. Fuzzy control is used to realize system modeling and parameter identification. The important problem that fuzzy system needs to solve is how to obtain it. How fuzzy rules and membership function problems improve the stability of fuzzy control, and also solve the problems of quantization methods, optimal selection of sampling period and automatic generation of membership parameters, because of the easy acceptance, simple design and robustness of fuzzy controllers [21]. Make fuzzy control more widely used. In the hydraulic system, the influence factors of the system are complex, nonlinear, time-varying, and large random interference. It is not easy to establish a mathematical model of the system. Fuzzy control is widely used in this respect. Fuzzy control is actually a kind of nonlinear control, which belongs to the category of intelligent control [22].

2.2.2. The Basic Idea of Fuzzy Control

The basis of fuzzy control is fuzzy mathematics, and the realization of fuzzy control is computer. Fuzzy control is to imitate the way people think, does not depend on the mathematical model of the controlled object, and obtains the output control amount through the method of fuzzy reasoning [23].

2.2.3. Control Principle and Composition of Fuzzy Controller

The principle block diagram of the fuzzy controller is shown in Figure 1. The fuzzy controller is mainly composed of the following:

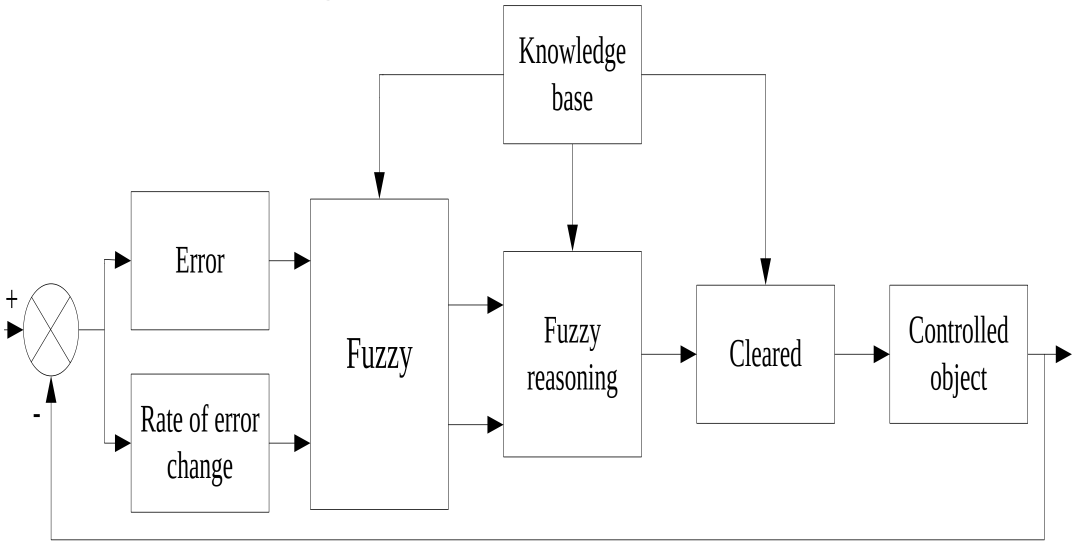


Figure 1. Block diagram of fuzzy control

(1) Fuzzification

The work of fuzzification is to convert the precise quantity of input into the amount of fuzzification, and transform the processed input quantity into appropriate scales, and then change it to the range of the respective domain and then perform fuzzy processing to become fuzzy quantity. And represented by the corresponding fuzzy set.

(2) Knowledge base

Including database and fuzzy control rules, the database includes the membership function of each variable, the scale transformation factor and the fuzzy space grading number. Fuzzy control rules include a series of control rules expressed by fuzzy linguistic variables, reflecting the knowledge and experience of experts.

(3) Fuzzy reasoning

It is the core of the fuzzy controller and has the ability to simulate human fuzzy reasoning.

(4) Clarification

Its function is to transform the fuzzy quantity into the clear quantity in the domain and the scale transformation into the actual control quantity. The clear calculation mainly includes the maximum membership function method, the median method and the weighted average method. The so-called maximum membership function method is based on the principle of maximum membership degree, and the maximum value of the membership function is selected as the clear value. The median method is to take the area enclosed by the membership function of the fuzzy set and the area enclosed by the abscissa axis into two parts as the judgment result. The weighted average method takes a weighted average as a clear quantity output, as in equation (1), where:i is the domain element; u_i is the membership.

$$u_a = \frac{\sum_{i=-s}^{s} i \times u_i}{\sum_{i=-s}^{s} u_i} \tag{1}$$

The fuzzy control system is mainly composed of a fuzzy controller, an input and output circuit, a controlled object, and a sensor. The fuzzy controller is actually a microcomputer, which can select single-chip microcomputer, industrial computer, etc., input and output circuits such as raster interface cards, D/A cards, and so on. The object to be controlled is a hydraulic servo system or the like. Designing fuzzy controllers must solve three key problems: fuzzification of input quantities; establishment of membership functions, fuzzy control rules or fuzzy control tables; fuzzy decision of output information.

The determination of the membership function is itself objective. The membership function is subjective for each person, usually based on experience or statistics, or given by an authority. The membership function is determined by the following three aspects, fuzzy statistical method, exemplified method and expert experience method. Common membership functions are triangles, normal shapes, trapezoids, and so on.

2.2.4. Reasons for Using Fuzzy Control

As an intelligent control strategy, fuzzy control has its unique advantages over conventional control. The specific performance is as follows:

1) Fuzzy control does not require a systematic mathematical model, so it can achieve the advantages that conventional control can not achieve for time-varying, lag, and nonlinear systems.

2) Strong stability and strong anti-interference. Because the sensitivity of fuzzy control to error changes is reduced, the system will not be out of control in a large range.

3) It is easy to understand, simple, practical, easy to implement, and low in development cost. Its requirements for sensors are reduced, and it is easy to realize through fuzzy software and hardware.

2.3. Structure and Control System of Heave Compensation Simulation System

2.3.1. Heave Compensation System Simulation System Hardware Components

The hardware of heave compensation simulation experiment system is mainly composed of industrial computer, grating displacement sensor, grating sensor high-speed sampling interface card, D / a card, proportional controller, oil cylinder, proportional directional valve and its peripheral auxiliary circuit, as shown in Figure 2.

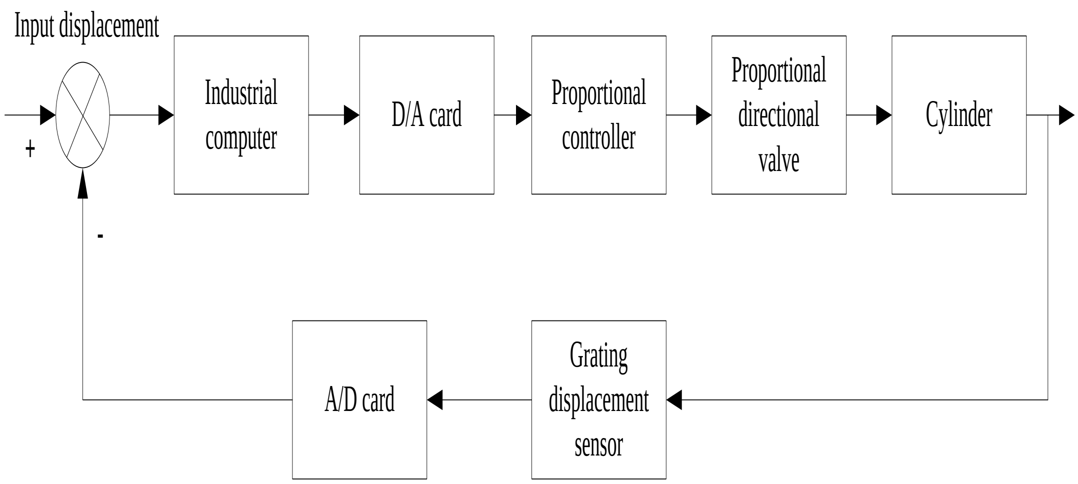


Figure 2. Block diagram of the hardware composition of the heave compensation system

2.3.2. Grating Displacement Sensor

The grating displacement sensor is used to detect the displacement of the compensation system cylinder, and it is sent to the grating SDC.2 interface card (four-way grating sensor high-speed sampling interface card) through the grating signal input connection line. The system adopts KA-3001200 linear grating. The ruler is mainly composed of a ruler and a readhead. The pitch is 0.001mm, the precision can reach 1pm, and the range is 300ram.

2.3.3. Raster Sensor High-Speed Sampling Interface Card

SDC.2 (four-way grating sensor high-speed sampling interface card) produced by a limited company is designed for grating sensor signal acquisition. The sampling data rate of each channel is up to 2.5MHZ. If the grating scale is 0.001mm resolution, then the sampling rate can reach above 120M/min, which can be used for high-speed moving displacement detection of CNC machine tools (CNC), and has a leading position in China. The introduction of this card greatly facilitates the development and production of various related inspection, positioning and control products, shortens the design and production cycle, and can meet the various needs of OEM product manufacturing, teaching experiments, scientific research institutions, etc., using this card as a hydraulic cylinder. Stroke detection, acquisition of displacement data of the grating displacement sensor. The technical feature is four-way raster data processing, which can be used for linear encoder data acquisition. The speed is up to 2.5MHZ, ISA bus interface, and the grating reference point coordinate value locking function is used for the reference point memory and recovery I/O address. The choice of jumper mode can select the address range from 200H to 3F0H, the factory default address is 320H.

X: represents the X axis, Y: represents the Y axis, Z: represents the Z axis, and W: represents the W axis.

J: Indicates that this axis is in the normal signal acquisition and display state.

F: Indicates that this axis is in the grating reference point search state.

H: Indicates that the axis has locked the reference point coordinates of the scale.

2.3.4. D/A Output Card

The D/A conversion card used is a PCL-726D/A output card produced by a company, which can output unipolar 0-5V, 0-10V and bipolar voltage -5-5V, -10-10V, and with 4 to 20 mA current, the card features six independent D/A output channels, a 12-bit double buffered D/A converter, 16-bit inputs and 16 digital outputs. All D/A outputs will be in the initial state of 0 after reset or voltage on in any bipolar or unipolar mode.

The I/O port base address can be selected by an 8-bit DIP switch. The PCL-726 card requires 16 consecutive addresses in the I/O address space. Valid from address 200H to 3F0H, the factory default address is 2C0H, the address can be adjusted by changing the jumper position. The digital bit is divided by 8 bits and the corresponding base address is incremented by 0 and the lower 8 bits are added to the corresponding base address by 1 corresponding address output.

2.3.5. Electro-hydraulic Proportional Valve Electric Controller

The BD-SE-1000/20 proportional controller is a proportional power amplifier. It mainly consists of voltage regulator, ramp generator, step function generator, output current limiter, 200HZ sine oscillator and two controllable constant current generators. The power supply voltage is AC220V, the power is 40VA, the control voltage minimum load resistance is 500Ω, the maximum output current is 800/1000mA, the maximum load resistance is 30Ω, the first conductive current is 100mA, the dither frequency is 200HZ, and the initial current of the electromagnet is 100mA. The ramp time is 1s.

Its main function is to receive the differential mode voltage output of the D/A converter card or the manually adjusted voltage output. After power amplification, it is converted into a current control proportional valve electromagnet A, and B moves the spool to control the output flow rate.

2.3.6. Proportional Directional Valve

A three-way four-way proportional directional valve from a company is used. Model 4WRAE6E1-15-2X/G24K31/A1V with built-in amplifier with a diameter of 6mm, rated flow of 151/min, given input range of -10-10V, electrical signal in the form of analog DC voltage or current, the maximum current of the electromagnet is 2.5A, and the power supply voltage is 24V.

Pin assignment of component plug: A is connected to 24V DC, B is connected to GND, D is the input COM value plus or minus 10V or 4-20mA, and E is the reference voltage terminal.

The working principle is that the input voltage is controlled by the sum of the amplifier and the ramp generator and the step function generator and converted into a current proportional electromagnet. When the electromagnet is not energized, the spool remains in the neutral position. When the proportional electromagnet is energized, it will directly push the spool. The displacement is proportional to the electrical signal. The electromagnet loses power and the spool is pushed back to the neutral position, thus changing the flow and direction.

2.3.7. Pump

It adopts double pump YBI-16/16, which has the advantages of small pressure pulsation and long service life. Its nominal displacement q=16/16mL/r, speed n=960r/min, rated pressure p=6.3Mpa, flow rate (at rated pressure) 13.6L/min, volumetric efficiency $\eta \geqslant 85\%$, driving power W=2.0Kw.

3. Experiments

3.1. Experimental Environment

The experimental system uses a hydraulic cylinder to simulate the change of the ocean wave, which is controlled by the proportional directional valve 1. It can generate the required displacement change, and drive the channel steel with four cylinders up and down. The industrial computer can simulate various speed and displacement sine waves and changes in sea conditions. Two of the following four cylinders are compensation cylinders, two are passive cylinders connected to the pump, and the compensation cylinders are controlled by proportional directional valves 2, 3. When the hydraulic cylinders 1 move up (down), the grating displacement sensor 2 outputs one. In the positive (negative) direction change signal, in order to achieve the purpose of the heavy object under the cylinder, the output voltage of the industrial computer makes the proportional directional valve 2, 3 work in the right (left) position, and supplies oil to the lower (upper) cylinder. , output a displacement that changes in the negative (positive) direction, thus achieving the purpose of heave compensation.

3.2. Experimental Heave Motion Signal Acquisition

According to the zero wavefront theory, when the water depth and the wavelength ratio d/X are greater than 1, the wave height is greatly attenuated and close to zero. Here, it is considered that there is a "zero wavefront" can be considered zero. Imagine placing a reference object at the zero wave surface as an absolute reference point for the signal acquisition system. Three ultrasonic receivers are placed on a horizontal surface at the bottom of the mining vessel. By measuring the distance from the transmitter to the receiver, the geometric relationship can be utilized. It is convenient to find the heave signal and the drift value of the horizontal position at a certain moment of the mining ship. The heave motion signal of the offshore building is detected by the ultrasonic transmitting and receiving method.

3.3. Heave Motion Signal Simulation

A mining vessel can be approximated as a simple harmonic motion under the action of waves. It can be regarded as a sinusoidal motion, that is, $y = A\sin\omega t$, where y is the amplitude and ω is the angular frequency. In light load, the amplitude can be 50 mm, the angular frequency can be 0.5 radians/second, and the amplitude is in the heavy load. Take 20 mm and the angular frequency is 0.5 radians/second.

4. Discussion

According to a large number of experiments, fuzzy control is successful in the application of the heave compensation system. It has the advantages of incomparable classical PID control, and has the advantages of fast response speed and small steady-state error. Classic PID control needs to be adjusted according to different mathematical models parameter. There is a contradiction between response time and overshoot. Fuzzy control does not need to know the mathematical model of the controlled system to achieve good control results. It combines with PID control to complement each other and each has its own advantages. In this experiment, a total of five control algorithms were implemented, namely classical PID control, small discrete level fuzzy control, large discrete level fuzzy control, fuzzy PID composite control, and fuzzy self-tuning PID control experiment.

4.1. Experimental Analysis

4.1.1. Step Response Analysis of Various Control Algorithms

The steady-state error of various control algorithms under the condition of heavy load of 210 kg step signal is 100 mm. As shown in Table 1, it can be seen from the experiment that the steady state accuracy and anti-interference ability of the classic PID control are not suitable for individual.

Applied to the heave compensation system, the fuzzy self-tuning PID control significantly improves the steady-state accuracy of the system. Large discrete-level fuzzy control has higher precision and response speed than small discrete-level control, while fuzzy PID composite control combines the advantages of both, with faster accuracy and faster response speed. The anti-interference ability, the smaller the threshold, the more obvious the effect of fuzzy control. The steady-state error maps of various control algorithms are shown in Figure 3.

Table 1. Steady-state steady-state error tables for various control algorithms

Classic PID	Small level blur	Large level blur	Self-setting PID	Fuzzy PID composite
-2.856	-0.893	-0.201	-0.639	-0.04

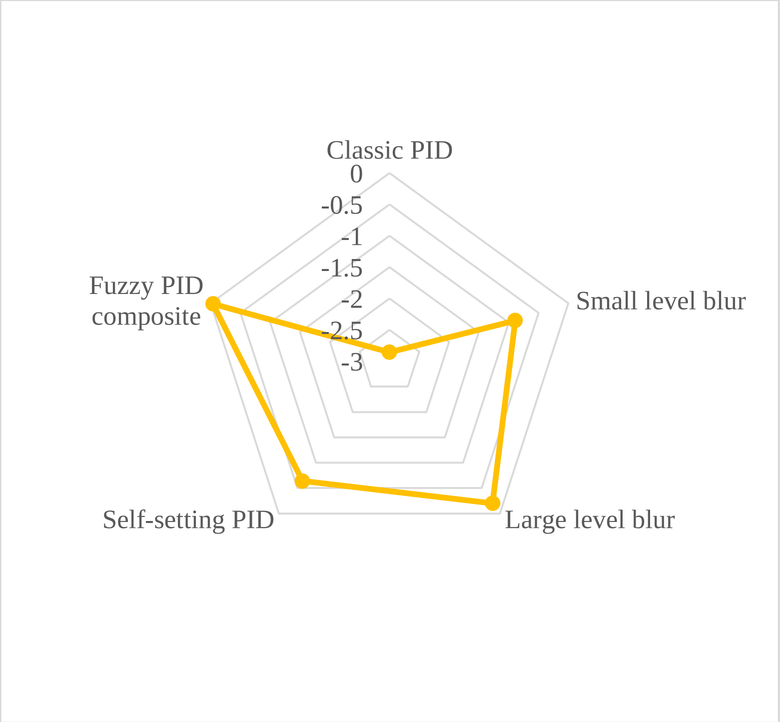
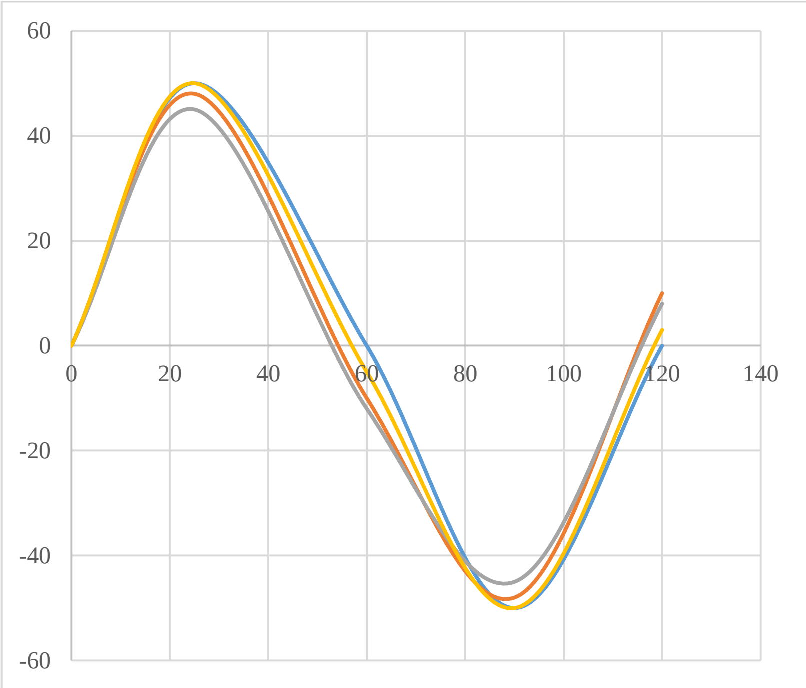


Figure 3. Steady-state error maps for various control algorithms

4.1.2. Sinusoidal Response Analysis of Various Control Algorithms

The ideal twist line is a sinusoid with an amplitude of 50 mm and a frequency of 1 rad/s. Applying various controllers for sinusoidal tracking is shown in Figure 4. It can be seen that the tracking curve lags the actual curve and has a better commutation. Large hysteresis, which is caused by the dead zone of the proportional valve, can pass the dead zone through the dead zone compensation or feed forward control voltage. The performance of the cylinder drop is poor and not very stable. It can be improved by taking different values of the controller parameters when the cylinder rises and falls. It can be seen that the fuzzy PID composite control has good tracking accuracy when the cylinder is lowered.



Blue:PID control Orange:Fuzzy control
Gray:Fuzzy PID composite control Yellow:Fuzzy self-tuning PID control

Figure 4. Sine tracking diagram for various control algorithms

4.2. Experimental Analysis of Various Control Algorithms Applied in the Heave Compensation Simulation System

The absolute mean of various control algorithms is shown in Table 2. The variance table is shown in Table 3. It can be seen that the fuzzy control improves the compensation accuracy and reduces the fluctuation component of heavy load and light load, compared with the classic PIO, it has more advantages in the control of hydraulic system.

Table 2. Absolute mean tables for various control algorithms

Absolute mean	PID	Fuzzy self-tuning PID	Small level blur	Large level blur	Threshold value 2 fuzzy PID composite	Threshold value 1 fuzzy PID composite
Light load	2.4385	2.1835	2.411	0.8002	0.8345	0.8307
Overload	2.0645	1.160	1.1262	0.8304	1.1478	1.0478

Table 3. Variance tables for various control algorithms

Variance	PID	Fuzzy self-tuning PID	Small level blur	Large level blur	Threshold value 2 fuzzy PID composite	Threshold value 1 fuzzy PID composite
Light load	7.3406	6.0284	10.2400	0.8577	0.8581	0.847
Overload	5.0477	1.6313	1.6176	0.5450	0.8403	0.4134

4.2.1. Experimental Analysis of Light Load Heave Compensation System

Using the upper cylinder as the simulated mining vessel movement, using the classic PID control, and the following four cylinders as the compensation cylinder, it can be seen that the classic PID control displacement is between -4.5 and 4.5 mm, while the fuzzy self-tuning PID control displacement is between -4.2 and 2.2 mm improves the accuracy of PID control. It can be seen in the fuzzy control with different discrete levels that the large discrete level fuzzy control is obviously higher than the precision of the small discrete level control. It can reach -1.7 to 0.5 mm, greatly improving its accuracy. In the fuzzy PID composite control, the precision of the threshold value of 1 mm is -1.7 to 0.5 mm, and the precision is slightly higher and stable than the threshold of 2 mm. The smaller the threshold value, the more obvious the fuzzy control effect and the higher the stability. The overall experimental curve is shown in Figure 5.

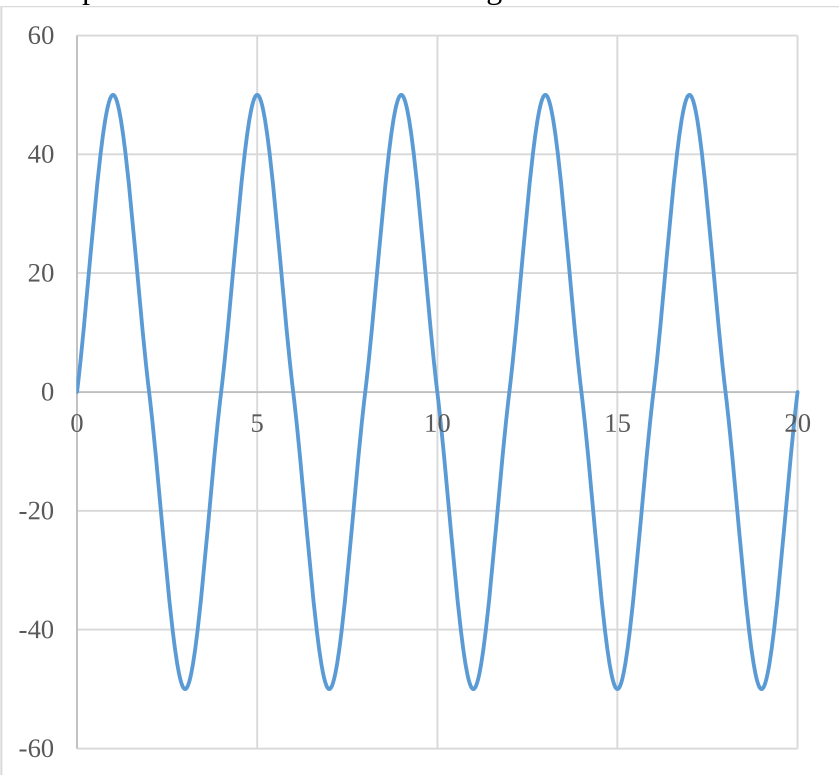


Figure 5. Light load various control compensation curves

4.2.2. Experimental Analysis of Heavy Load Heave Compensation System

Compensation 210 kg of heavy weight under the cylinder constitutes the heavy load heave compensation experimental system. The overall experimental curve of various control algorithms is shown in Figure 6. The fuzzy self-tuning PID control improves the performance of the classical PID control, and the precision is improved. The level fuzzy control is obviously higher than the small discrete level fuzzy control, and the accuracy of the large discrete level can reach -2 to 0.5 mm. The fuzzy PID composite control with a threshold of 1 is more stable than the fuzzy PID composite control with a threshold of 2.

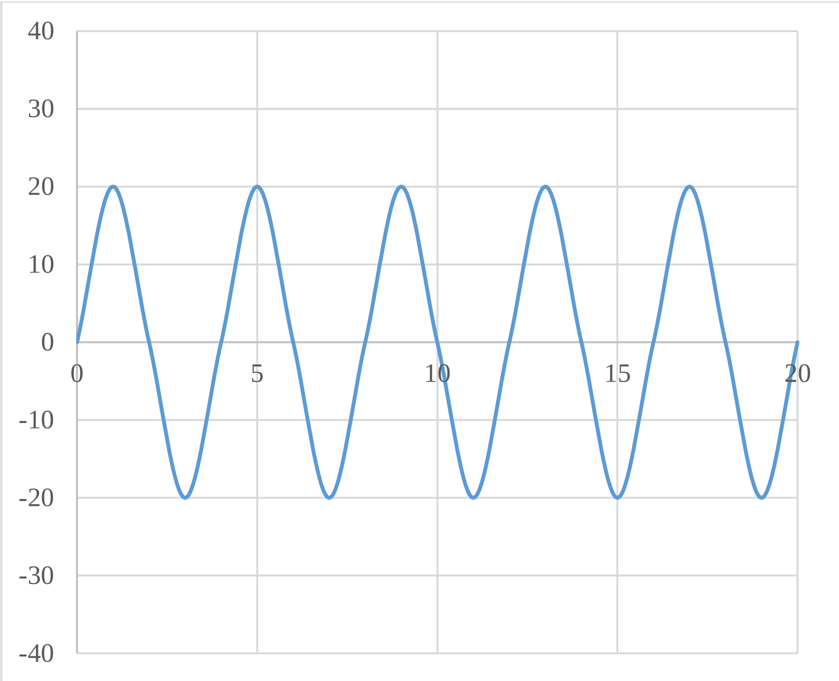


Figure 6. Heavy duty control compensation curves

5. Conclusion

This paper is based on a large number of references. This paper proposes a novel experimental structure principle, excellent control equipment (IPC, proportional valve), and new control method (fuzzy control). The simple and practical programming language (VB) realizes the control strategy, adopts modular structure and is easy to modify. Combining MATLAB's SIMULINK and fuzzy toolbox for simulation analysis, it opens up a new path for the combination of experiment and simulation. This experiment and its research results directly serve the offshore engineering deep sea mining technology.

This paper does not need to establish a mathematical model to make full use of fuzzy control, and has the characteristics of self-adaptive ability and robustness. The advantages and disadvantages of various fuzzy control algorithm control are analyzed. The comparison between large discrete level fuzzy control and small discrete level fuzzy control, the comparison of fuzzy control and fuzzy PID composite control, the comparison of fuzzy PID composite control under different threshold conditions, fuzzy self-tuning PID compared with the classic PID control, it can be seen from the simulation and experimental results that the fuzzy control has the incomparable advantages of the classic PID, and has great improvement in adjustment time, dynamic precision, maximum overshoot and adaptive ability. It maintains good adaptive ability and robustness in complex sea conditions with variable frequency, variable amplitude and variable load. According to the experimental results, fuzzy control can not eliminate the steady-state error, and in the case of inaccurate parameter adjustment, it is easy to produce oscillation. Therefore, combining it with the classic PID control can make the strength and avoid weakness, so that it has both high response speed and small steady-state error.

In this thesis, the feasibility of fuzzy control is studied, but there is still insufficient precision. The fuzzy control is easy to generate oscillation in the local. The sampling time interval of the system is long, which affects the control effect. It also needs to be further improved in control precision and response speed. The fuzzy parameter tuning PID control effect studied by this system is not ideal. This is related to the parameter adjustment range and fuzzy control rules and membership function. The PID control parameters still need further adjustment and trial in the experiment. The threshold of fuzzy PID hybrid control needs further adjustment. The system approximates the wave P-M spectrum signal, although it generally mimics the changing law of the waves. However, there is still insufficient precision and the data is not accurate. It is recommended to collect real-time ocean wave signals on the mining vessel as simulated wave signals, and further improve the control strategy. System software features and interfaces need to be further improved.

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Data Availability

Data sharing is not applicable to this article as no new data were created or analysed in this study.

Conflict of Interest

The author states that this article has no conflict of interest.

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