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Application of Adaptive Fuzzy PID Leveling Controller

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Abstract

Aiming at the levelling precision, speed and stability of suspended access platform, this paper put forward a new adaptive fuzzy PID control levelling algorithm by fuzzy theory. The method is aided design by using the SIMULINK toolbox of MATLAB, and setting the membership function and the fuzzy-PID control rule. The levelling algorithm can real-time adjust the three parameters of PID according to the fuzzy rules due to the current state. It is experimented, which is verified the algorithm have better stability and dynamic performance.

Keywords: *fuzzy PID, suspended access platform, levelling, Simulink*

1. Introduction

With the development of construction industry in urban and rural areas in China, the suspended access platform is used more and more popular in the area of curtain wall construction, bridge maintenance, repair and maintenance of fan and so on, which has some advantages such as simple structure, flexible use and convenient to remove and pack. It is significative that research of the levelling of suspended access platform. If the inclined suspended access platform is not timely levelled, the suspended access platform will overturn, which is horrible [1], [2]. Aiming at the situation, this paper put forward a adaptive fuzzy PID control levelling algorithm applied to suspended access platform.

2. The Strategy of Leveling System

The levelling system uses chasing levelling [3]. The highest hoisting point keep static and the other hoisting points will not be adjusted in order until all the hoisting points' height are same, as shown in Figure 1. To improve the efficiency and ensure the safety, we need the suspended access platform levelling time short and levelling not jitter. Because the speed of hoister v is a constant, if decrease the levelling time t, the speed v must increase, which is easily lead to overshoot; if speed v is decreased, the levelling time t will be long. When levelling initial the dip angle is big the speed v is set big and when the dip angle small, we set the speed v small, this is the best levelling strategy. This strategy not only ensures the levelling precision but also improves the efficiency and stable [4]. The control object of system model is made up of platform lean degree and levelling mechanism of platform. The levelling system is closed loop control system, the input parameters are the difference of the two incline and the change rate of the difference of the two incline, the output parameters is the speed of the hoister.

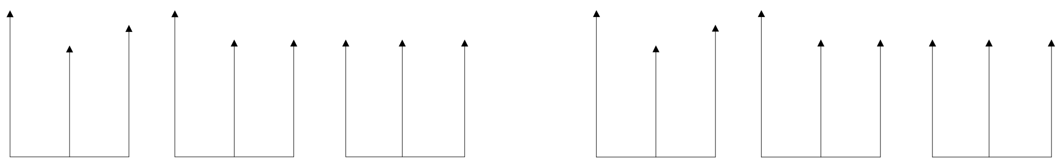
(a) (b)

Figure 1. The strategy of chasing levelling

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3. The Design of fuzzy-PID Controller

3.1. The Structure of Adaptive Fuzzy PID Controller

Fuzzy-PID controller can automatically adjust the proportional coefficient K_P, integral coefficient K_I, and differential coefficient K_D according to different situations of error $e(k)$ and error rate $e_c(k)$. This achieves the adaptive control of system, and it can make system have good dynamic and static performance. The structure of adaptive fuzzy PID controller is shown in Figure 2.

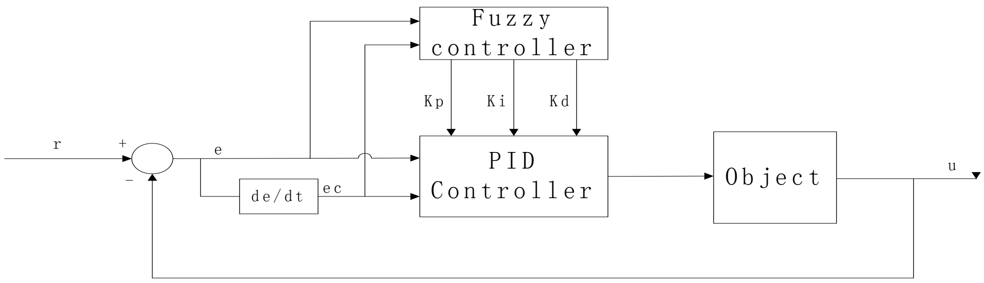

Figure 2. The structure of adaptive fuzzy PID controller

There are five input parameters in the PID controller, which are $e(k)$, $e_c(k)$, K_P, K_I, K_D. The output parameter is $u(k)$. The ideal control algorithm model is that:

$$u(k) = K_P\left[e(k) + \frac{1}{T_I}\int e(k)dk + T_D\frac{d_{e(k)}}{dk}\right] \quad (1)$$

To convenient the computer analyse, this paper uses constant sampling period T, we make $k = nT$ and $u(k) \approx u(nT)$, $e(k) \approx e(nT)$, $\int_0^k e(k)dk \approx T\sum_{i=0}^{n} e(iT)$, $\frac{d_{e(k)}}{dk} \approx \frac{e(nT)-e(nT-T)}{T}$ and which are applied to (1):

$$u(nT) = K_P\left\{e(nT) + \frac{T}{T_I}\sum_{i=0}^{n} e(iT) + \frac{T_D}{T}\left[e(nT) - e(nT-T)\right]\right\} \quad (2)$$

We make $K_I = K_P\frac{T}{T_I}$, $K_D = K_P\frac{T_D}{T}$ and which are applied to (2):

$$u(nT) = K_P e(nT) + K_I\sum_{i=0}^{n} e(iT) + K_D\left[e(nT) - e(nT-T)\right] \quad (3)$$

$$u(k) = K_P e(k) + K_I\sum_{i=0}^{n} e(iT) + K_D\left[e(k) - e(k-1)\right] \quad (4)$$

PID increment $\Delta u(k)$ is that:

$$\Delta u(k) = u(k) - u(k-1) = K_P\left[e(k) - e(k-1)\right] + K_I e(k) + K_D[e(k) - 2e(k-1) + e(k-2)] \quad (5)$$

In the equation, $e(k)$, $e_c(k)$ are error and error rate separately of the first k sampling time, $u(k)$ is output parameter of the first k sampling time; T_I, K_D are integral time constant and differential time constant separately; T is sampling period; K_P, K_I and K_D are the proportional coefficient, integral coefficient and differential coefficient separately.

We can know how to adjust the system itself when the $e(k)$, $e_c(k)$ change according to the effect of K_P , K_I and K_D . When $e(k)$ is too large, the system have larger error, which must be eliminated as soon as possible no matter the $e_c(k)$ is what. So the proportional coefficient K_P should take large value, and K_I should take small value to prevent the overturn because of $e_c(k)$ too large, and K_I should take small value to less time; When $e(k)$ is medium, the value of K_P should decrease, K_I should increase and K_D is medium; When $e(k)$ is small, K_P , K_I should increase to keep system have good dynamic performance, the value K_D of depend on $e_c(k)$ to prevent system shake [5], [6], [7].

3.2. The Adaptive Fuzzy PID Controller

The adaptive fuzzy PID algorithm is based on PID algorithm. It detects the value of error $e(k)$ and error rate $e_c(k)$ and adjusts the K_P , K_I and K_D ,according to the fuzzy rules. In the fuzzy PID controller the input parameter is $e(k)$ and $e_c(k)$, and output parameter is K_P , K_I and K_D . This paper set the fuzzy PID algorithm by FUZZY toolbox of SIMULINK in MATLAB.

Fuzzy language description of input and output parameter

The basic range of error $e(k)$ and error rate $e_c(k)$ multiply the quantization factor K_e and K_c separately, and then can get the fuzzy subset range $[-5,5]$

$$e, e_c = \{-5,-4,-3,-2,-1,0,1,2,3,4,5\}$$

The fuzzy subset is $e, e_c = \{NB, NM, NS, 0, PS, PM, PB\}$. The fuzzy subset of output parameter is $\{NB, NM, NS, 0, PS, PM, PB\}$, and the fuzzy subset range is $[-5,5]$ .The membership function is triangle; the membership function of input and output parameter is shown Figure 3 and Figure 4.

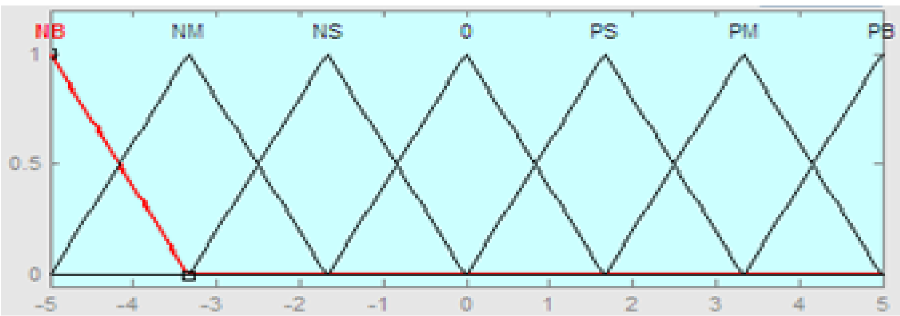

Figure 3. Membership function curves of input parameter

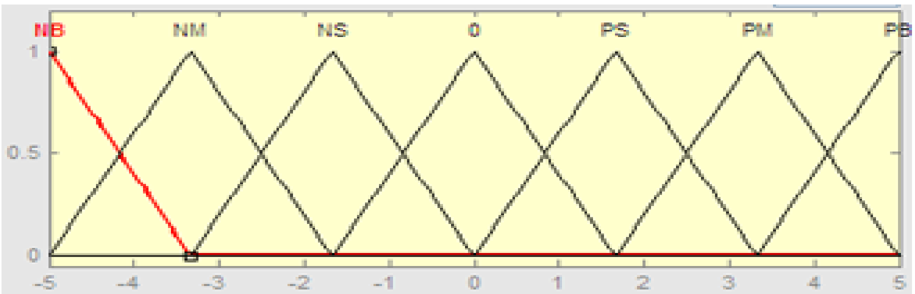

Figure 4. Membership function curves of output parameter

Fuzzy rules are the most important parts of fuzzy controller [8]. According to parameter adjustment basic rules of the 3.1 section in this paper and the operational experience of field engineering person, we make the fuzzy rules table. System automatically set K_P, K_I and K_D depend on different e and e_c .The fuzzy rules Table1, Table2 and Table3 are shown. K_P, K_I and K_D three-dimensional chart and the full fuzzy rules as shown in Figure 5, Figure 6, Figure 7, Figure 8.

We can know the corrected parameters from the fuzzy rules charts, and use ambiguity resolution algorithm to get the exact value applied to (6):

$$\begin{cases} K_P = K_P^{'} + \Delta K_P \\ K_I = K_I^{'} + \Delta K_I \\ K_D = K_D^{'} + \Delta K_D \end{cases} \quad (6)$$

$K_P^{'}$, $K_I^{'}$, $K_D^{'}$ are the initial PID parameters, ΔK_P, ΔK_I, ΔK_D ,are output parameters of fuzzy controller, K_P, K_I and K_D are the final control parameters.

Table 1. Fuzzy Rule Table of K_P Rules

Kp / e \ ec	NB	NM	NS	0	PS	PM	PB
NB	PB	PM	PM	PM	PS	ZO	ZO
NM	PB	PB	PM	PS	PS	ZO	NS
NS	PM	PM	PM	PS	ZO	NS	NS
0	PM	PM	PS	ZO	NS	NM	NM
PS	PS	PS	ZO	NS	NS	NM	NM
PM	ZO	ZO	NS	NM	NM	NM	NM
PB	ZO	ZO	NM	NM	NM	NB	NB

Table 2. Fuzzy Rule Table of K_I Rules

Ki / e \ ec	NB	NM	NS	0	PS	PM	PB
NB	PB	PB	PM	PM	PS	ZO	ZO
NB	PB	PB	PM	PS	PS	ZO	NS
NS	PM	PM	PM	PS	ZO	NS	NM
0	PM	PM	PS	ZO	ZO	NS	NM
PS	ZO	PS	ZO	NS	NS	NS	NM
PM	ZO	ZO	NS	NM	NM	NM	NB
PB	ZO	ZO	NM	NM	NM	NB	NB

Table 3. Fuzzy Rule Table of K_D Rules

Kd ec / e	NB	NM	NS	0	PS	PM	PB
NB	NB	NB	NM	NM	NS	ZO	ZO
NM	NB	NB	NM	NS	NS	ZO	ZO
NS	NB	NM	NS	NS	ZO	PS	PS
0	NM	NM	NS	NS	PS	PM	PM
PS	NM	NS	ZO	ZO	PS	PM	PB
PM	ZO	ZO	PS	PS	PM	PB	PB
PB	ZO	ZO	PS	PM	PM	PB	PB

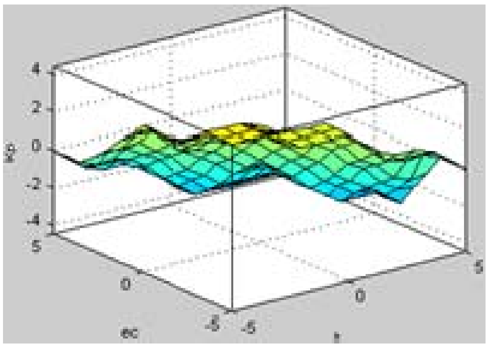

Figure 5. Three-dimensional chart of K_P rules

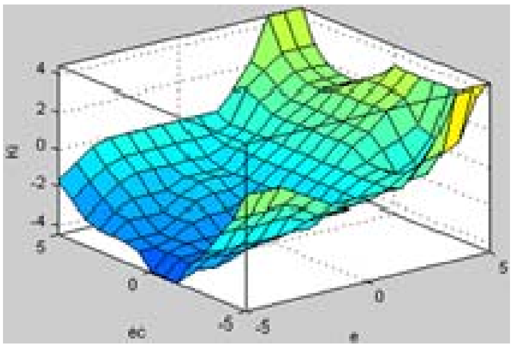

Figure 6. Three-dimensional chart of K_I rules

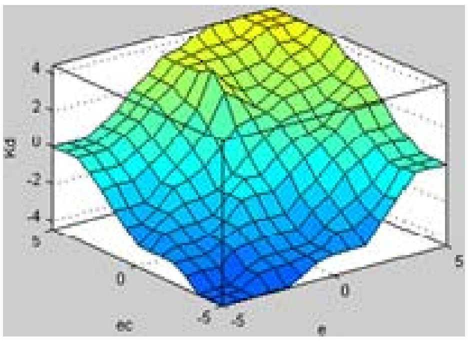

Figure 7. Three-dimensional chart of K_D rules


Figure 8. Chart of fuzzy rules

4. Simulation Analysis and Experiment Analysis
4.1. Simulation Analysis

In order to test the fuzzy PID levelling algorithm better, this paper analysis fuzzy PID levelling algorithm by Simulink module library of Matlab.

This paper uses the Simulink basic tool box and Fuzzy logic tool box. The fuzzy logic tool box of Simulink includes Fuzzy module, Mf-edit module, Rule-edit module, Surf-view module [9], [10]. This system combines with Fuzzy Logic Controller, and concludes the simulation module chart of Fuzzy PID controller. The chart is shown in Figure 9.

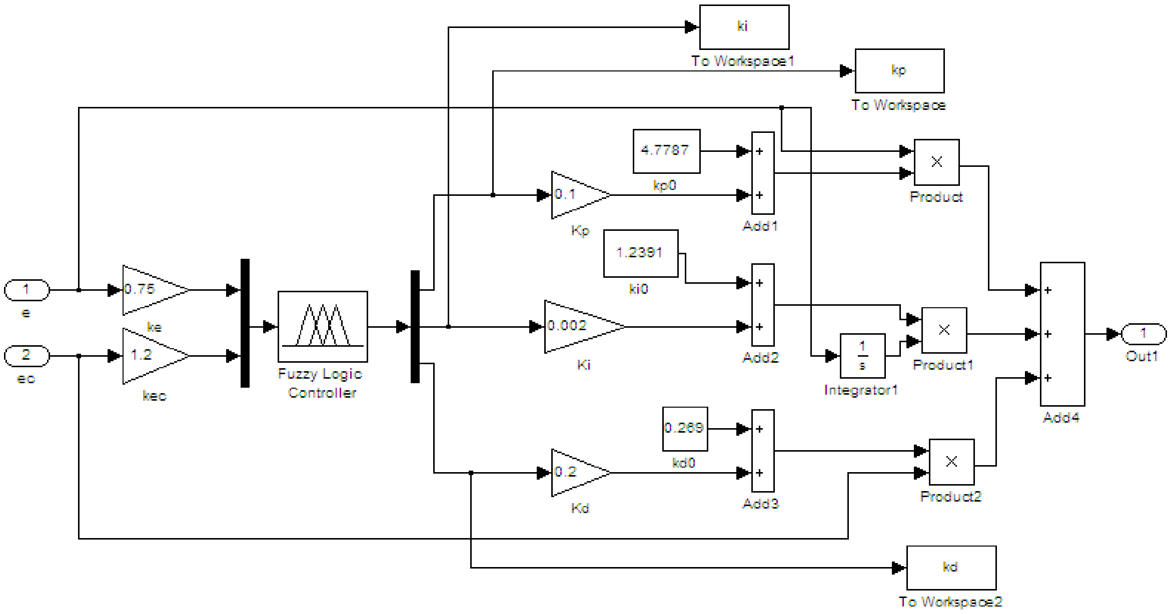

Figure 9. Simulation module of Fuzzy PID controller

The inputs scale factors of Fuzzy PID controller K_e and K_{ec} are 0.75 and 1.2.The outputs scale factors of Fuzzy PID controller $K_{\Delta K_P}$, $K_{\Delta K_I}$ and $K_{\Delta K_D}$ are 0.1, 0.02 and 0.2. In order to observe the change in real time, the proportional coefficient ΔK_P , integral coefficient K_I and the differential coefficient ΔK_D are output to the workspaces. The simulation module is encapsulated in a box; this box is shown in Figure.10.

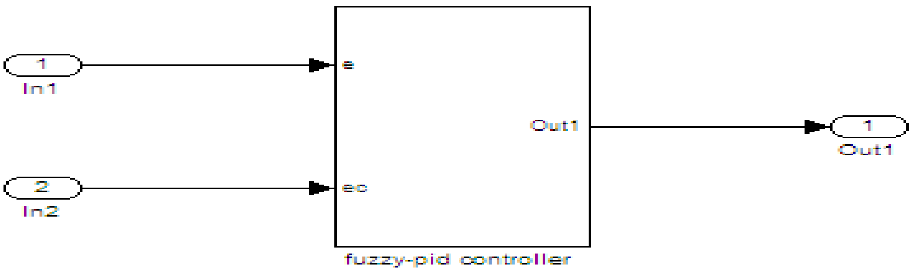

Figure 10. Fuzzy PID controller package module

This paper not only simulates the fuzzy PID levelling algorithm, but also simulates the PID levelling algorithm. And the simulation system includes interference module, by which can analysis the anti-interference ability of fuzzy PID levelling algorithm. The simulation module chart is shown in Figure 11.

The simulation time of this system is 5s, and the sample frequency is 0.01s. First, test the step response of fuzzy PID levelling algorithm and PID levelling algorithm. Second, add a step perturbation to the load end of system at 1.5s, which can analysis the anti-interference ability and stability of two algorithms. The initial control parameters of PID levelling algorithm are that $K_P^{'}$ is 4.7787, $K_I^{'}$ is 1.2391 and $K_D^{'}$ is 0.269. The values of parameters are acquired by Ziegler-Nichols method. The transfer function of this system is $G(s)=\frac{522500}{s^3+87.60s^2+10471s+1}$. The step response curves are shown in Figure 12, and the interference curves are shown in Figure 13.

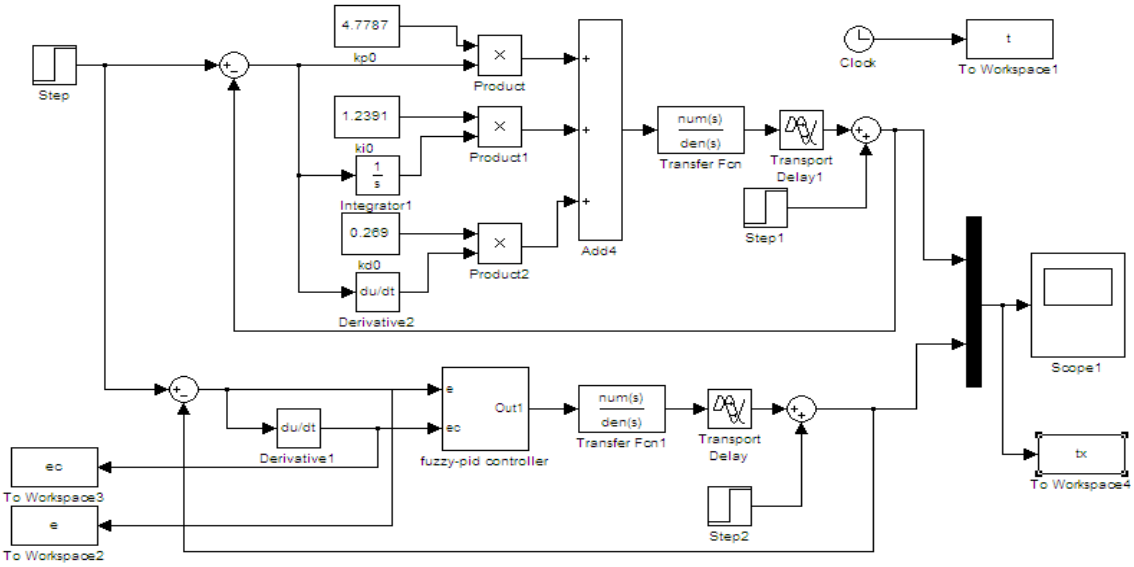

Figure 11. Simulation module of suspended access platform leveling

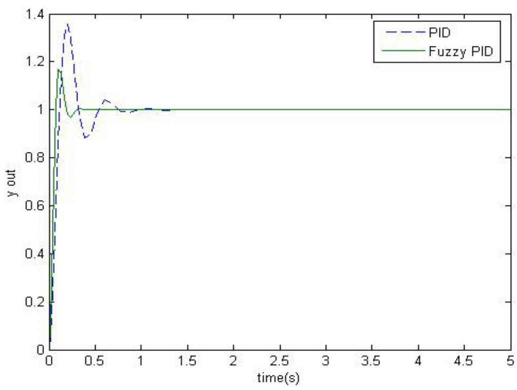

Figure 12. The step response curve of fuzzy PID and PID

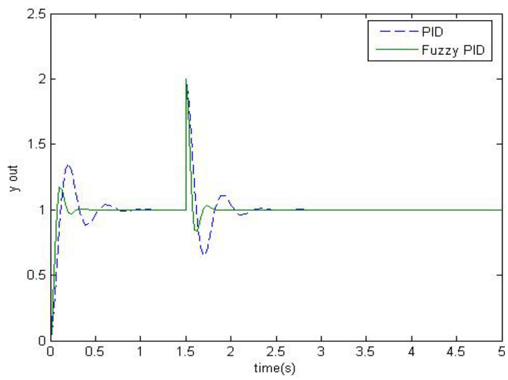

Figure 13. The disturbance characteristics curve

The curve of error, curve of error variety and the curve of ΔK_P , ΔK_I , ΔK_D are shown in Figure 14 - Figure 18.

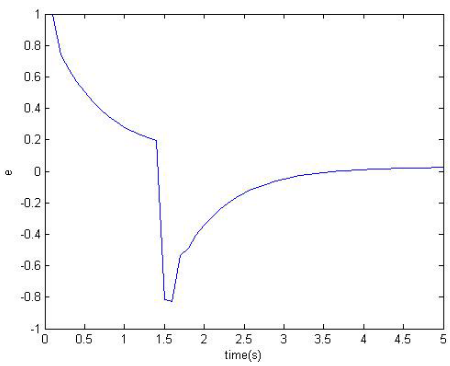

Figure 14. The curve of error

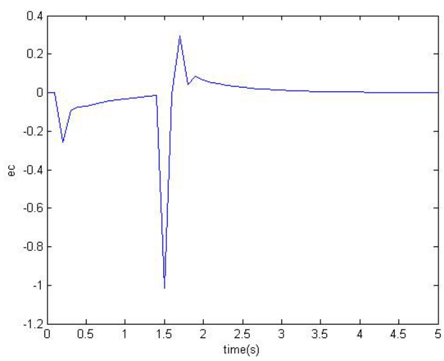

Figure 15. The curve of error variety

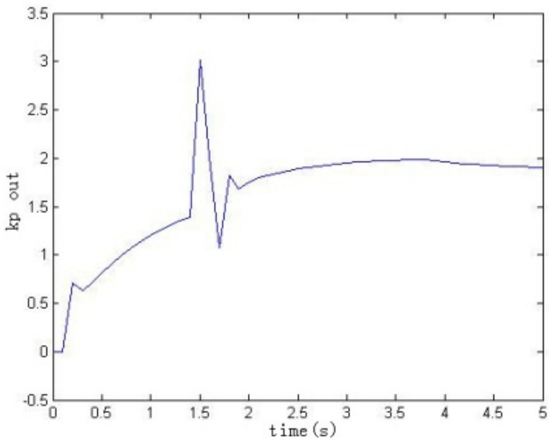

Figure 16. The curve of ΔK_P

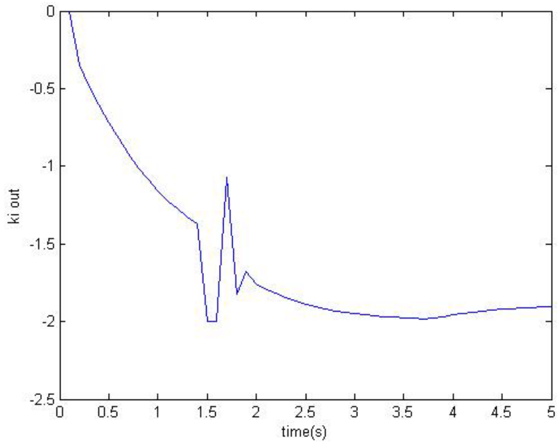

Figure 17. The curve of ΔK_I

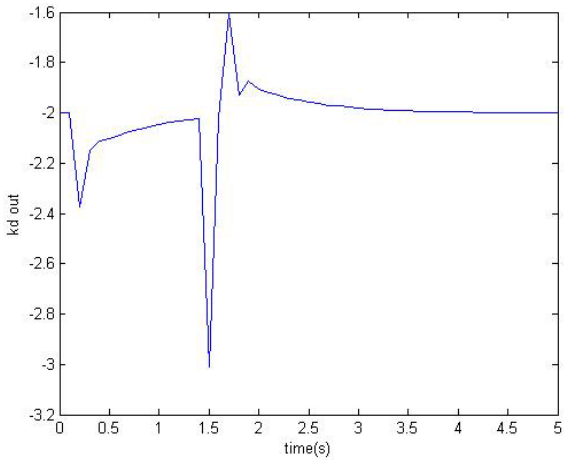

Figure 18. The curve of ΔK_D

The response time of Fuzzy PID levelling algorithm is about 0.5s, the response time of PID levelling algorithm is about 1.5s. And Fuzzy PID levelling algorithm is better than PID levelling algorithm in anti-interference ability and stability.

4.2. Experiment Analysis

In order to more visually and exactly analysis the control effect of fuzzy PID levelling control algorithm, the article introduced an aerial platform of the levelling system for the field experiment. The fuzzy PID control compared with traditional PID control of their two different levelling algorithms in the levelling system of the actual levelling effect [11]. In this experiment, the two levelling algorithm levelling time and accuracy are recorded. The results are shown in the Figure 19 and Figure 20.

Figure 19 is the curves of adaptive fuzzy PID levelling curve and Figure 20 is the curves of PID levelling curve. The X levelling initial Angle of two control methods are 4 degree, the Y is -4 degree.

The Figure 19 and Figure 20 can reach the conclusion that: 1. the fuzzy PID levelling control mode compared with the traditional PID level control have greatly improved in the levelling precision, fuzzy PID level control accuracy for ± 1 degree, traditional PID level control accuracy for ± 1.5 degree, overshoot is greatly decreased. 2. in single direction levelling process, when the levelling direction Angle oscillate, the fuzzy PID levelling control mode of oscillation amplitude is far less than the traditional PID levelling generated concussion amplitude, it illustrates that in levelling process using fuzzy PID control method of big is better than traditional PID control mode; 3. on the levelling time, the fuzzy PID levelling need 2s-2.5s in single direction levelling, the whole levelling process 4.5s-5s , traditional PID levelling need 4s-4.5s in single direction levelling and the whole levelling process for 9s-9.5s, levelling time reduced by 50%.

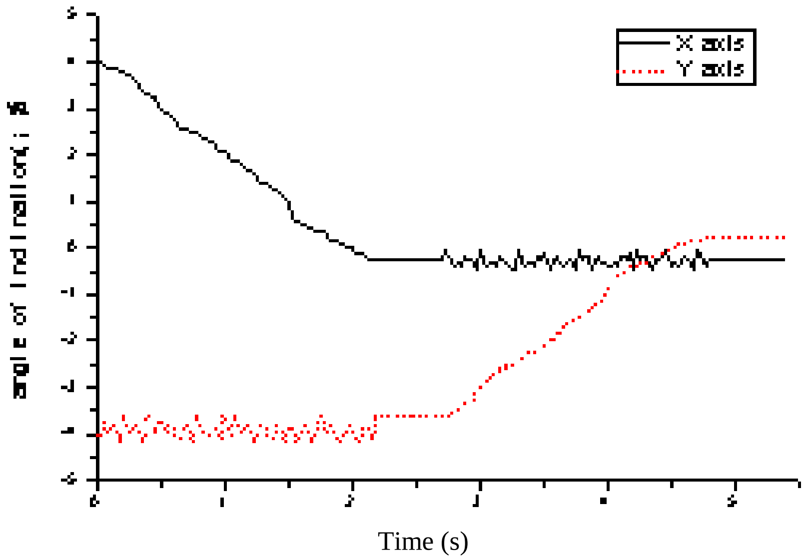

Figure 19. The curves of adaptive fuzzy PID levelling

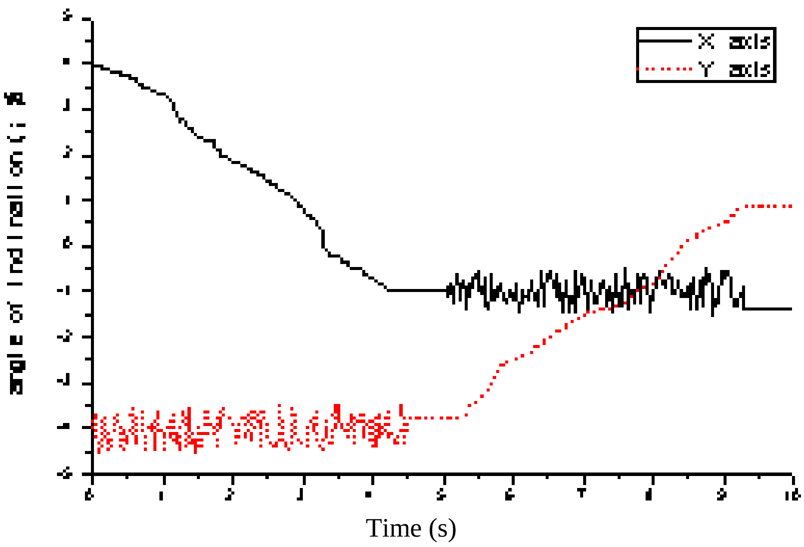

Figure 20. The curves of PID levelling

In levelling start stage, these differences to minimize dip error is given priority to because of fuzzy PID control method of fuzzy rules, to control frequency converter increase hoist speed, when the dip reduced, control error is given priority to, control frequency converter to reduce hoist speed, in order to reduce overshoot, so use this kind of level control method can improve levelling accuracy, shorten the levelling time, increase the levelling process stability.

5. Conclusion

This paper sets algorithm parameters and design of fuzzy control rules by using MATLAB SIMULINK toolbox. Adaptive fuzzy PID levelling algorithm can online and real-time adjust the three parameter K_P, K_I and K_D in the PID algorithm, realize optimization control, make the system's precision and rapidity and stability are greatly improved. Through the theoretical analysis and the test, the adaptive fuzzy PID levelling algorithm for the aerial platform can satisfy the aerial platform levelling needs.

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