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FUZZY PID TRACKING CONTROLLER FOR TWO-AXIS AIRBORNE OPTOELECTRONIC STABILIZED PLATFORM

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Abstract. *In this paper, a novel fuzzy PID control scheme based on tracking controller of the azimuth/elevation loop is presented to improve the accuracy of tracking real-time target. The fuzzy PID controller consists of three fuzzy logic controllers and a PID controller with model reference adaptive control, in which adaptive gains of three parameters of PID controller are being fine-adjusted by fuzzy logic rules. The membership functions (MFs) of the proposed control algorithm are different from general algorithms, in which the MFs of input and output are distinct from each other, such as MF types, numbers of MFs and display ranges. The performance of the proposed fuzzy PID control approach is compared with ordinary PID control algorithm. Simulations are performed to verify the validity of tracking performance performed with fuzzy PID control model, which has better transient performance with zero overshoot, and fast convergence towards tracking capabilities. Fuzzy PID tracking control algorithm can promote the performance of the overall system, which can lay the theoretical foundation for deeply researching control system based on the airborne optoelectronic stabilized platform.*

Keywords: Fuzzy-PID, Tracking controller, Optimization scheme, Stabilized platform

1. **Introduction.** The optoelectronic stabilized platform [1] is widely applied in detecting and tracking dynamic target. The line of sight (LOS) of sensor is susceptible to cause shake under outside interference in tracking targets, so it is controlled in a specific manner to segregate outside rotating, while tracking controller plays a decisive part when line of sight (LOS) keeps stable in inertial space. The better controller can improve the performance of the whole control system, the improvement of tracking controller will inevitably promote the reliability of tracking and detecting real-time sensitive targets. So the research of fuzzy PID control algorithm has positive significance of airborne photoelectric stabilized platform.

Fuzzy [2] PID control is an indispensable intelligent control algorithm in today's era, which is a kind of control theory that PID algorithm combined with fuzzy control theory. Three parameters of k_p, k_i and k_d are continuously detected, and online tuned according to fuzzy control rules, and the iteration procedures are not terminated until the dynamic and static performances meet the requirements of the different inputs to control parameters. It is commonly applied in many fields such as injection molding, chemical engineering, metallurgy, and power systems [3]. There has been a new trend of precision guidance recently because of the excellent tracking control ability. So it is a thorny task to search a better MFs scheme for fuzzy PID control.

In 1965, fuzzy mathematics and the basic concept of fuzzy system, fuzzy control and theoretical basis were created in [4, 5]. The first fuzzy controller was established in 1974, which led to the development of fuzzy control applications in [6]. There were some classic control algorithm researches during this period, the high speed and precision track control systems applying velocity/acceleration error compensation approach were proposed, and the photoelectric track precision was lifted in [7]. Disturbance observer was proposed in the inner loop of semi-strapdown seeker servo-control system in order to elevate tracking precision, and the performance of the proposed algorithm was greatly improved via MATLAB simulations in [8]. Lead-PI controller, LQG/LTR controller was conducted, and simulation results testify the validity of the control design procedures in [9]. The compound-axis tracking servo control system was presented, which had two servo control loops, and simulation results showed that the proposed method was effective and had higher tracking precision in [10]. Parameters of LuGre friction model for gimbal axis were obtained with the method of two-step identification and dynamic parameter optimization, and the tracking performance was verified by simulation and experimental results in [11]. Robust controllers combined with optimization were used to control the outer loops, which was efficient by simulations in [12]. A scheme about co-simulation of mechatronic system was presented to optimize control parameters of a two-axis inertially stabilized platform system (ISP) applied in an unmanned airship (UA), which was effective to obtain optimized ISP control parameters according to virtual prototyping (VP), eventually leading to the better control performance in [13]. The model identification and common PID controllers were proposed to track strategy, and simulations proved the validity of tacking strategy in [14]. A compound control method was employed to achieve better control performance for a two-axis inertially stabilized platform (ISP), and simulation results tested that the proposed compound control approach can obtain high control precision in [15]. The PID controller of tracking system was designed using the inverse system method, and comparison study indicated that the results were better in [16]. The proposed optimized PID controller had been designed, and simulation results proved that it provided better track effect in [17]. The analysis solution relationship of fuzzy controller and traditional controller was strictly established in the fuzzy control theory and proved the variable gain nonlinear PID controller about Mmadani fuzzy PI or PID, which established the bridge for the combination of fuzzy control theory and traditional PID control theory in [18, 19]. A method based on fuzzy PID controller was presented, and the results proved the validity in [20]. Fuzzy PID controller was constructed based on the tracking loop of three-axis frames, and the results validated that the overral stabilization tracking control system had better robustness and tracking precision in [21]. However, the membership functions (MFs) types of the proposed control algorithm are not the conventional trapmf and gaussmf, but also the hybrid scheme of trapmf and zmf, moreover, the rules of the input and out function are superior to the traditional, the number of the conventional MFs input and output rules is odd number, such as 3, 5, 7 and 9, but the 6 and 8 rules are utilized in this fuzzy PID control scheme. Besides, there are diverse display ranges $[-6, 6]$ and $[-10, 10]$ of whether the input or output MFs. [22, 23, 24].

Motivated by the aforementioned discussions, the core contributions of this work are as follows. Firstly, the tracking control algorithm is the focus of research, which can strength the transient performance of the overall control system. Last but not least, our main concern is the efficacy according to establishing the novel control algorithm including the MFs types of input, output variables and the number of MFs, which is superior to the ordinary controller design schemes. Besides, the hybrid types of trimf and trapmf are utilized, which outperforms the traditional means. Some illustrative numerical examples are further provided to demonstrate the efficacy of the proposed control approaches.

The rest of this paper is organized as follows. The control object model and the rate gyro model are presented in Section 2. Section 3 offers the tracking control system. The fuzzy PID control model is conducted in Section 4. Section 5 puts forward the fuzzy

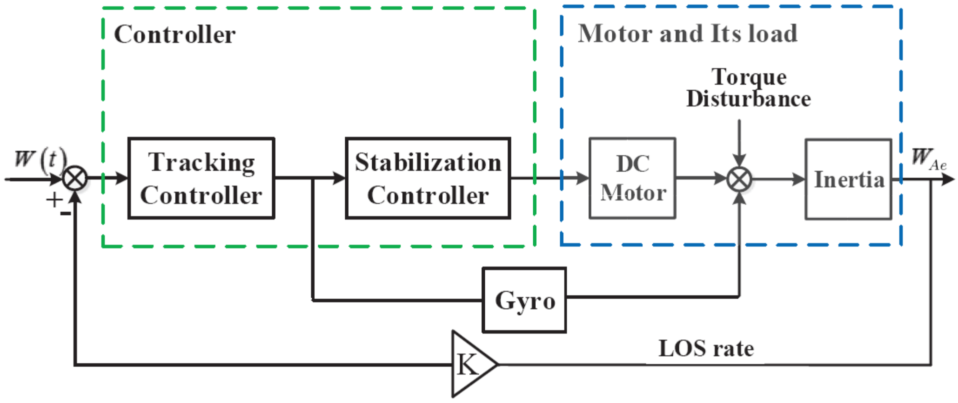


FIGURE 1. Tracking control system of two-axis optoelectronic platform ($W(t)$ is the reference input signal, W_{Ae} represents the output signal)

PID tracking control algorithm design of azimuth/elevation loop. Contrasting simulation experiments are enforced in Section 6. Section 7 summarizes the conclusions.

2. **The Tracking Control System.** Outer gimbal axis is built on the two stents through the brackets, the stents and base are fixed together, torque motor is installed at one end of shaft, driving the rotation of the shaft. The encoder is fixed on the other end of the shaft in order to measure the casing of outer frame relative to rotation angle. The shaft is built on the outer frame by the bearing for inner frame, and the torque motor is installed on one end of the shaft. The angular rate gyro is installed on the inner frame to measure the rotating angular velocity of inner frame to the inertial space. Detector is installed on the inner frame. Outer frame is the roll frame, and the inner frame is pitch frame.

The servo control of the stabilized platform is made up of torque motor, angular velocity gyro, gyro control circuit, encoder, image tracking circuit and digital servo control circuit. The infrared optical system, infrared detector, components and angular velocity gyroscope are installed on the elevation frame, the gyro sensitive axis is perpendicular and orthogonal, the movement of sensitive platform is relative to the inertial space in the direction of the roll and elevation, the signals are speed feedback, so the circuit realizes stability. The encoder can obtain the angle location information of the roll and pitch axis so as to realize the angle position closed loop, the image tracking circuit will calculate the LOS angle error of the yaw and pitch according to the infrared image information errors, the errors are transmitted into the control circuit by coordinate transformation, and the tracking loop control is realized.

In Figure 1, the overall control system contains sensor, rate gyro, DC motor, stabilization controller and tracking controller. The tracking controller is the focus of research work, and an unconventional fuzzy PID control scheme is utilized in tracking controller.

The sensor is conventionally installed to keep the LOS stabilized by suspending it on the inner gimbal of the optoelectronic stabilized platform. A rate gyro fixed on the inner gimbal is employed to measure the angular rates. The DC motor driving system contains two stabilization loops on the inner (elevation) and outer (azimuth) gimbals. The stabilization controller is established to make the optical axis of photoelectric detector stabilize in inertial space, while the position tracking controller is located on the outer of the speed stabilization loop corresponding to the body coordinate system, the control targets of the position loop are available when the body attitude changes, and the attitude of photoelectric detector under body coordinate system still sustains stabilized.

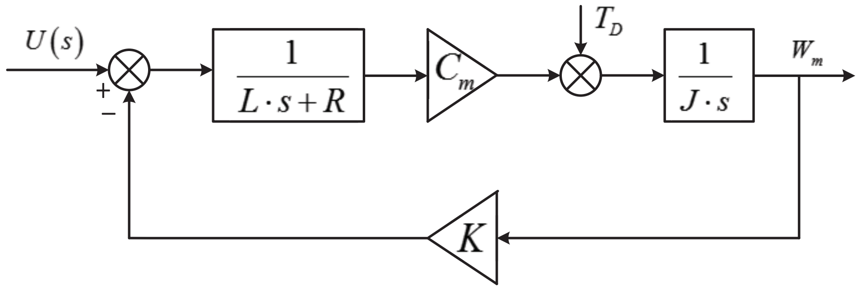


Figure 2. The block diagram of motor and load

Taking the inner gimbal for example, the detectors and sensors of the stable platform are fixed on the optical axis. The velocity feedback of the closed-loop control is formed. The role of the position loop is obtaining angular position control signal, controlling spool, realizing the closed-loop angle tracking. The stabilization controller and position tracking controller are utilized to isolate the outside disturbances and keep the LOS stabilized in inertial space. The motor parameters and its load are obtained by three-dimensional PROE model.

- Controlled object model

The control model of DC motor and load model [25] is as shown in Figure 2.

In Figure 2, $U(s)$ represents the motor armature voltage, R stands for the equivalent resistance of the motor armature, and L denotes the equivalent total inductance of the armature. J stands for the rotational inertia of the motor. K represents back-EMF coefficient, C_m is moment coefficient of the motor, and W_m denotes the angular velocity of motor rotation shaft.

In Figure 2, the transfer function of motor and load is depicted as follows:

$$W_m = \frac{C_m}{(R + L \cdot s) \cdot J \cdot s + C_m \cdot K} \tag{1}$$

- Rate gyro model

The rate gyro is utilized to measure the rates of azimuth and elevation frame, whose model is employed in [10]. The transfer function of rate gyro is a second order system, and its expression is as follows:

$$G_g(s) = \frac{\omega^2}{s^2 + 2\xi \cdot \omega \cdot s + \omega^2} \tag{2}$$

where $\omega = 50$ stands for natural frequency, and $\xi = 0.7$ denotes damping ratio.

- Stabilization and tracking controller

Stabilization controller is proposed to isolate external carrier disturbance and improve the stability of the control system. Tracking controller is presented based on the stabilized controller to track real-time targets, which has strong adaptive ability and can improve the dynamic performance of the overall system.

3. Control Schemes.

3.1. PID control.

PID is a linear controller, and their control deviation is a difference between given value $r_d(t)$ and actual output values $r(t)$.

$$E(t) = r_d(t) - r(t) \tag{3}$$

The control law is

$$u(t) = k_p \left[E(t) + \frac{1}{T} \int_0^t E(t)dt + \frac{T_d \cdot dE(t)}{dt} \right] \tag{4}$$

Its transfer function is

$$G(s) = \frac{U(s)}{E(s)} = k_p \left(1 + \frac{1}{T \cdot s} + T_d \cdot s \right) \tag{5}$$

Among them, k_p is proportionality coefficient, T stands for integration time constant, and T_d is differentiating time constant.

3.2. **Fuzzy logic control.** Fuzzy logic control mainly contained three parts, which are fuzzification, fuzzy inference and defuzzification.

3.2.1. *Fuzzification.* Fuzzification is actually an input interface of the fuzzy controller, which determines the input position deviation E and the rate of change EC of position deviation and transfers them into fuzzy quantity. There are gaussmf, gbellmf, trimf, zmf and so on in fuzzy control. However, the trapmf, zmf and the hybrid scheme of trapmf combined with zmf are applied, and their expressions are as follows.

- Trapezoidal-shaped membership function (Trapmf)

The trapezoidal curve is a function of vector x, and depends on four scalar parameters m, n, p and q, as given by

$$f(x; m, n, p, q) = \begin{cases} 0, & x \le m \\ \dfrac{x-m}{n-m}, & m \le x \le n \\ 1, & n \le x \le p \\ \dfrac{q-x}{q-p}, & p \le x \le q \\ 0, & q \le x \end{cases} \tag{6}$$

or, more capacity, by

$$f(x; m, n, p, q) = \max \left(\min \left(\frac{x-m}{m-m}, 1, \frac{q-x}{q-p} \right), 0 \right) \tag{7}$$

where the parameters m and n locate the "feet" of the trapezoid and the parameters n and p locate the "shoulders".

- Z-shaped membership function (Zmf)

This spline-based function of x is so named because of its Z-shape. The parameters m and n locate the extremes of the sloped portion of the curve as given by

$$f(x; m, n) = \begin{cases} 1, & x \le m \\ 1 - 2\left(\dfrac{x-m}{n-m}\right)^2, & m \le x \le \dfrac{m+n}{2} \\ 2\left(\dfrac{x-n}{n-m}\right)^2, & \dfrac{m+n}{2} \le x \le n \\ 0, & x \ge n \end{cases} \tag{8}$$

- Gaussian membership function (Gaussmf)

$$y = gaussmf\,(x, [sig\ c]) \tag{9}$$

$$f(x; \sigma, c) = e^{\frac{-(x-c)^2}{2\sigma^2}} \tag{10}$$

where σ and c are two parameters of Gaussmf. The parameters for gaussmf represent the parameters σ and c listed in order in the vector $[sig\ c]$.

3.2.2. *Fuzzy inference.* A lot of fuzzy conditional statements constitute fuzzy rule base such as "if (E is NB) and (EC is NB) then (U is NB)", the antecedent of conditional sentence is input and state, and the consequent of conditional sentence is control variable.

3.2.3. *Defuzzification.* The results are expressed by the language variable when the fuzzy inference ends, and the results of language variables must be converted to the actual value in order to utilize these. The above process is called defuzzification. Conventional schemes are centroid, mom, lom in solving the defuzzification, while the bisector is utilized in the proposed fuzzy controller. The bisector approach is regarded the median of $\mu_{c'}(z)$ as the defuzzification of z, that is $z_0 = df(z) = \mu_{c'}(z)$, and the expression is as follows:

$$\int_a^{z_0} \mu_{c'}(z)dz = \int_{z_0}^{b} \mu_{c'}(z)dz \tag{11}$$

4. **Fuzzy PID Control Model.** In Figure 3, the fuzzy PID control model emphasizes its importance to novel algorithm, such as the number of membership functions, the types of membership function, which can distinctly affect the performance of the whole tracking control system.

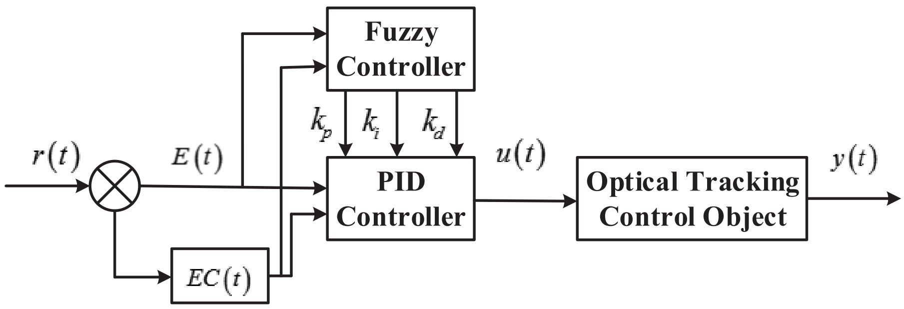


FIGURE 3. Fuzzy PID tracking controller system

The working flow chart of correction online is shown in Figure 4. The details of the flow chart are as follows.

(1) The initial value $r(t)$ is an input step signal of $[0, 1]$.

(2) The expressions of $E(t)$, $EC(t)$ are as follows:

$$\begin{cases} E(t) = r(t) - y(t) \\ EC(t) = E(t) - E(t-1) \\ E(t-1) = E(t) \end{cases} \tag{12}$$

where the initial value of $r(t)$ is 0, its final value is 1 and an input step signal, $y(t)$ is a controlled object of the discretization.

The control law is:

$$u(t) = k_p \cdot \left[E(t) + \frac{1}{T} \cdot \int_0^t E(t)dt + \frac{T_d \cdot dE(t)}{dt} \right] \tag{13}$$

(3) The fuzzization process of $E(t)$, $EC(t)$. The measuring value of the input variables is changed into a certain value of the fuzzy language. The membership functions are generally considered as the fuzzification functions.

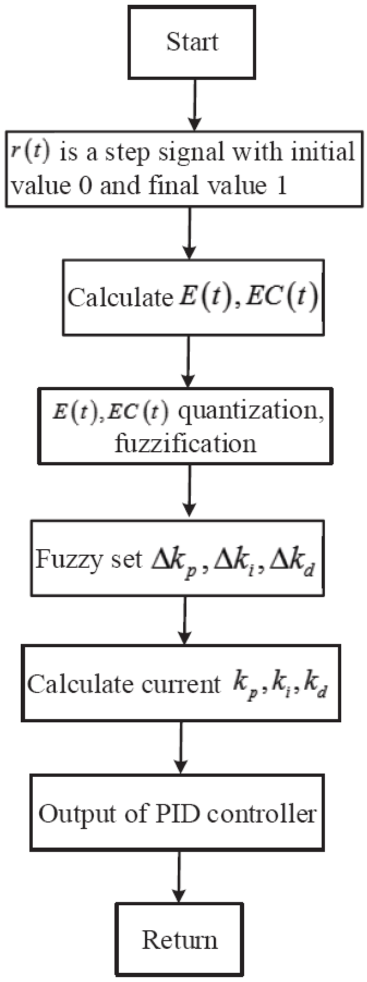


Figure 4. The working flow chart of correction online

(4) The outputs Δk_p, Δk_i and Δk_d are obtained from the membership degree functions, the fuzzy logic decides the outputs and its adjusting trend depends on the error values.

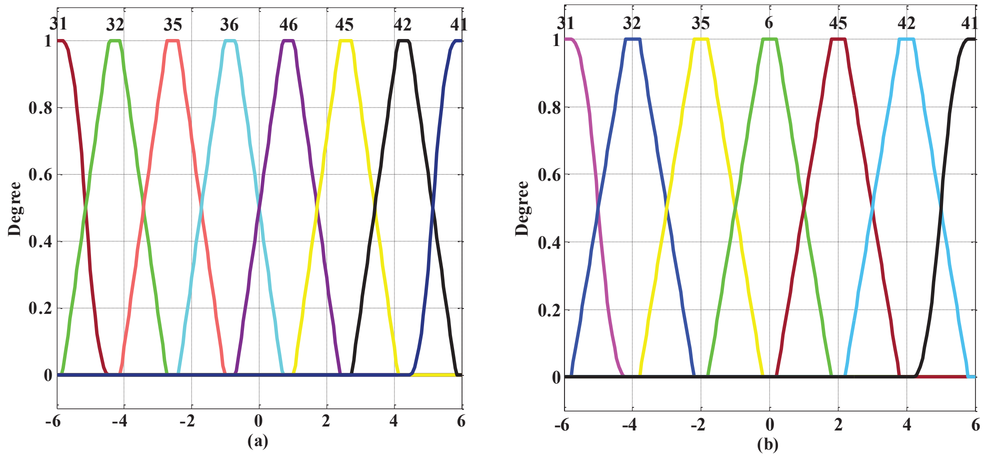
(5) The expressions of the current k_p, k_i, k_d are as follows.

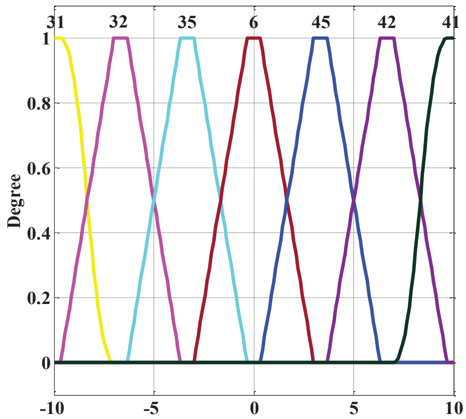
$$\begin{cases} k_p = k_p^{'} + \Delta k_p \\ k_i = k_i^{'} + \Delta k_i \\ k_d = k_d^{'} + \Delta k_d \end{cases} \tag{14}$$

where k_p, k_i and k_d are parameters of PID controller, $k_p^{'}$, $k_i^{'}$ and $k_d^{'}$ are initial setting parameters of PID controller, and Δk_p, Δk_i, Δk_d are adjustment variables.

The initial setting parameters $k_p^{'}$, $k_i^{'}$ and $k_d^{'}$ are obtained using the stable boundary method by MATLAB/SIMULINK, which are calculated based on the experience formulas by setting parameters values.

The variation ranges of E and EC are defined as the domain of the fuzzy set theory, which are shown as Figures 5-10, such as $[-6, 6]$ and $[-10, 10]$. The Big, Middle, Negative, Positive, Small and Zero are respectively substituted into the number 1, 2, 3, 4, 5 and 6. E, EC, the output of k_p, k_i, k_d and Δk_p, Δk_i, Δk_d are depicted in Figures 5-10 separately. So the membership degree and its values of fuzzy subsets are obtained, and Δk_p, Δk_i and Δk_d are obtained from the membership degree function. The current k_p, k_i and k_d are computed from Equation (14).





E/EC	31	32	35	6	45	42	41
31	41	41	41	41	42	45	6
32	42	42	45	45	45	6	6
35	42	45	6	6	6	35	32
62	45	45	6	6	6	32	31
46	31	32	6	6	6	45	42
45	32	35	6	6	6	45	42
42	6	6	45	42	42	41	41
41	6	45	41	41	41	41	41

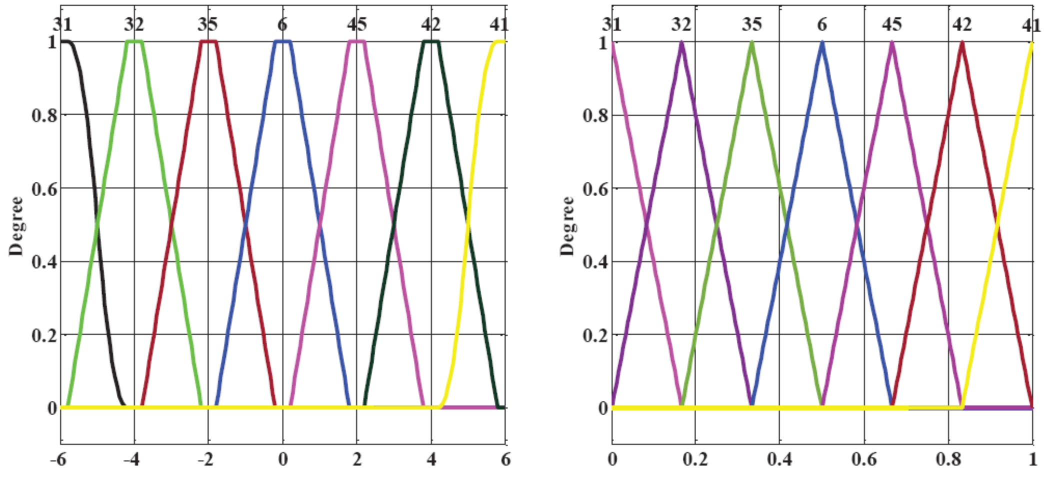
(c) (d)

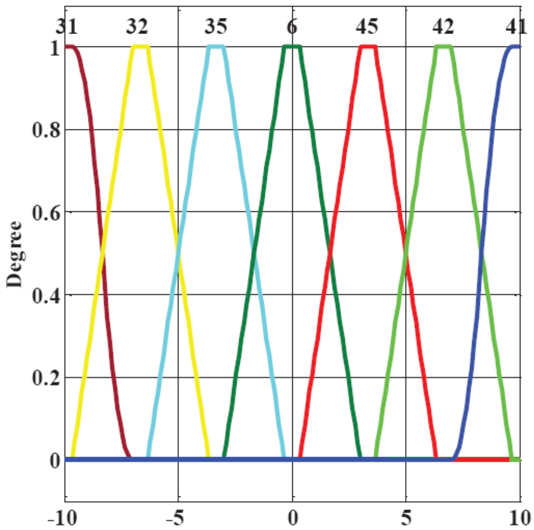
FIGURE 5. (a) The input E of Δk_p, (b) the input EC of Δk_p, (c) the output Δk_p, and (d) the rule base of Δk_p

5. **The Fuzzy PID Tracking Control Algorithm Design of Azimuth/Elevation Loop.** Fuzzy PID control approach is developed in tracking controller due to the excellent ability, the ordinary membership function [26] of input E, EC and output are 5*5, 7*7 or 9*9, the number of rules is 25, 49 or 81, the types of membership function are trimf, gaussmf or zmf, and the membership function of inputs E, EC and output is equal. While the membership function of the proposed fuzzy PID control in this paper has distinct inputs and outputs, such as the type and number of membership functions in Figures 5-10. The number 1, 2, 3, 4, 5 and 6 represents Big, Middle, Negative, Positive, Small and Zero.

- Algorithm 1

Three parameters k_p, k_i and k_d of PID controller are being fine-tuned online by three fuzzy controllers separately. The algorithm is important for the tracking performance, especially the types of membership function and the number of membership function. The membership functions of input about k_p are depicted in Figure 5(a), and there are eight membership functions including zmf and trapmf types. In Figure 5(b), seven zmf and trapmf membership functions are formulated. The types and numbers of output membership functions are the same as those of the input; however, the ranges of output variable are different from input variable's in Figure 5(c). Figure 5(d) depicts the fifty six rules of k_p membership function, which are distinct from general algorithm.





E/EC	31	32	35	6	45	42	41
31	41	41	41	41	42	45	6
32	41	41	41	42	45	6	6
35	41	42	45	45	6	35	32
6	32	35	6	6	6	35	32
45	32	35	6	45	45	42	41
42	6	6	45	42	42	41	41
41	6	45	41	41	41	41	41

(d)

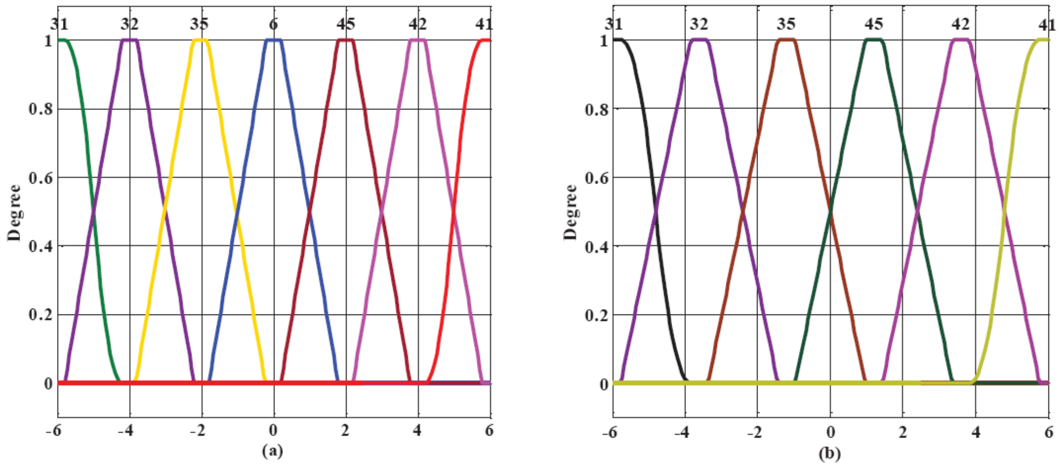
Figure 6. (a) The input E of Δk_i, (b) the input EC of Δk_i, (c) the output of Δk_i, and (d) the rule base of Δk_i

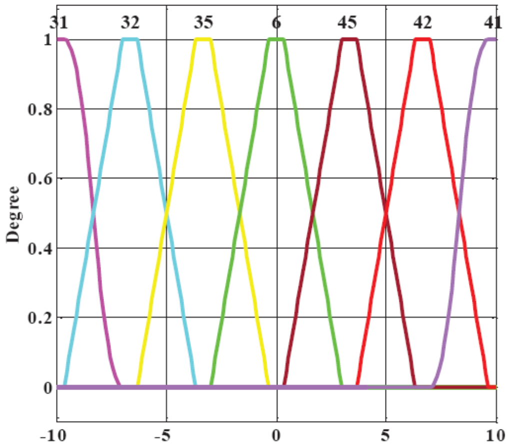
The ordinary seven trimf membership functions are employed and the range of input variables EC is $[0, 1]$, which has obvious differences toward others in Figure 6(b). The input E in Figure 6(a) and output in Figure 6(c) of k_i are identical to the input EC and output of k_p. There are forty nine rules of Figure 6(d).

In general, there are odd membership functions, such as three, five, and seven. However, six membership functions of input EC are generated, and the zmf and trapmf membership functions are applied in Figure 7(b). Figure 7(a) and Figure 6(a) have the equivalent conditions. The situations in Figure 7(c) are equal to those of Figure 6(c). There are forty two rules in Figure 7(d).

- Algorithm 2

The gaussmf membership functions are adopted while the numbers and rules of membership function are equal about k_p in Figure 8(a) and Figure 8(b).





E/EC	31	32	35	45	42	41
31	41	42	45	31	31	31
32	42	45	6	31	35	6
35	41	42	45	45	42	41
6	41	42	45	45	42	41
45	41	42	45	45	42	41
42	6	35	32	6	45	42
41	31	31	31	45	42	41

(d)

Figure 7. (a) The input E of Δk_d, (b) the input EC of Δk_d, (c) the output of Δk_d, and (d) the rule base of Δk_d

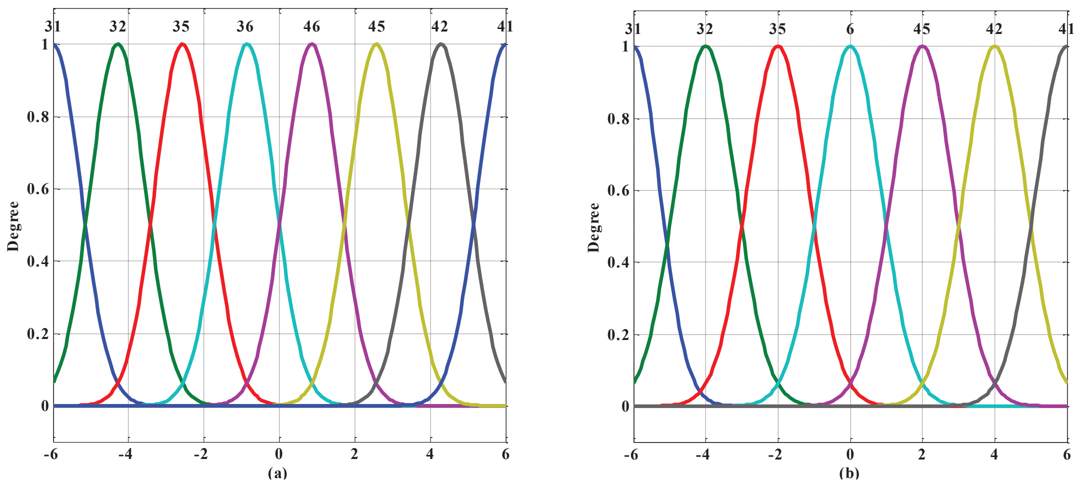


Figure 8. (a) The input E of Δk_p, and (b) the input EC and output of Δk_p

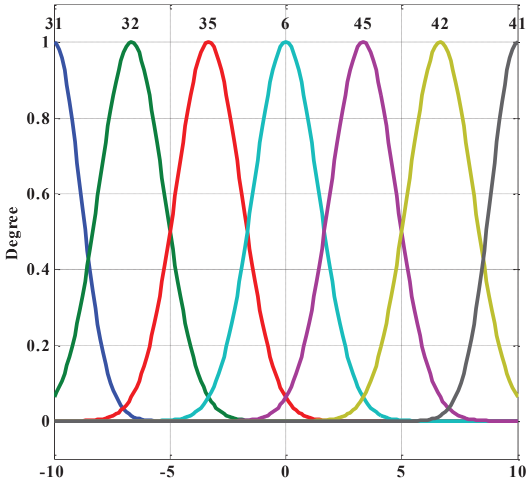
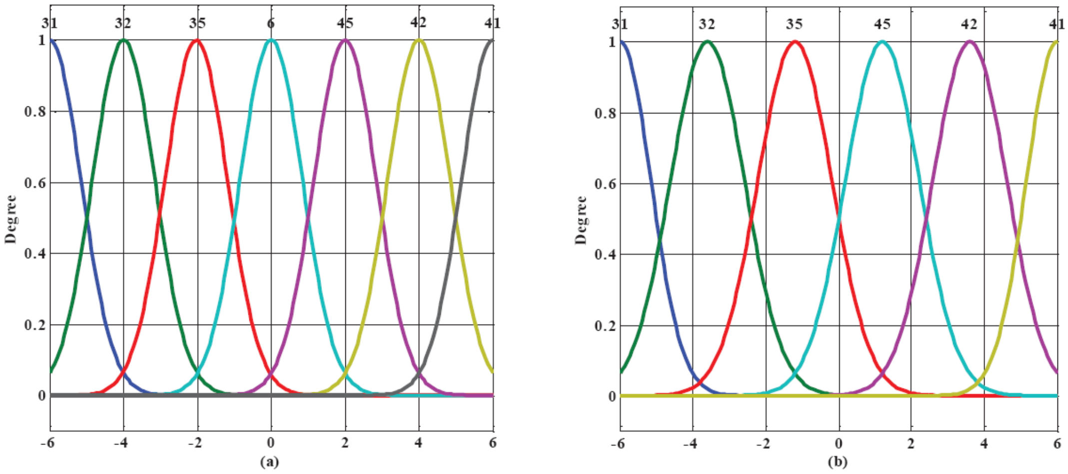


FIGURE 9. The input E and EC and output of Δk_i



E/EC	41	42	45	35	32	31
31	31	31	31	45	42	41
32	6	35	31	6	45	42
35	41	42	45	45	42	42
6	41	42	45	45	42	42
45	41	42	45	45	42	41
42	42	45	6	32	35	6
41	41	42	45	31	31	31

(c)

FIGURE 10. (a) The input E of Δk_d, (b) the input EC and the output of Δk_d, and (c) the rule base of Δk_d

The gaussmf membership functions are utilized, in which the numbers, rules and output of membership functions are equal about k_i in Figure 9.

In Figure 10(a), the gaussmf membership functions are put forward, and there are seven membership functions of input variable E and output of k_d. While the six membership functions of input variable EC are established in Figure 10(b). In Figure 10(c), there are forty two rules of k_d.

6. **Contrasting Simulation Experiments.** Three motor parameters are introduced in Table 1, which is obtained according to three-dimensional PROE model.

- Test 1: The control algorithm of azimuth/elevation loop under the parameter of motor model 1

Fuzzy PID-Fuzzy PID denotes stabilization controller and tracking controller are fuzzy PID controller, the former fuzzy PID stands for tracking controller, and the latter fuzzy PID represents tracking controller. Fuzzy PID-Fuzzy PID of tracking controller-stabilization controller has better performance than others, there is not over-shooting, the setting time is the least, and the step response of the azimuthal loop is shown in Figure 11. The parameters of controlling object transfer function are shown in Table 1. The comparative simulation results are shown in Table 2.

- Test 2: The control algorithm of azimuth/elevation loop under the parameter of motor model 2

The step response of the elevation loop is shown in Figure 12, Fuzzy PID-PID denotes tracking controller is fuzzy PID controller and stabilization controller is PID controller,

Table 1. Three motor parameters

Name	Model 1	Model 2	Model 3
Constant torque ($K_{TM}/(\text{N}\cdot\text{m/A})$)	0.004	0.028	0.065
Termination resistors ($Ra/(\Omega)$)	6	6.3	7.7
Inductance ($L_a/(\text{H})$)	0.0003	0.00079	0.00154
The moment of inertia ($J_m/(\text{kg}\cdot\text{m}^2)$)	0.085e-5	1.2 e-5	1.2 e-5
Counter electromotive force coefficient ($K_e/(\text{v}/(\text{rad/sec}))$)	0.072	0.24	0.028

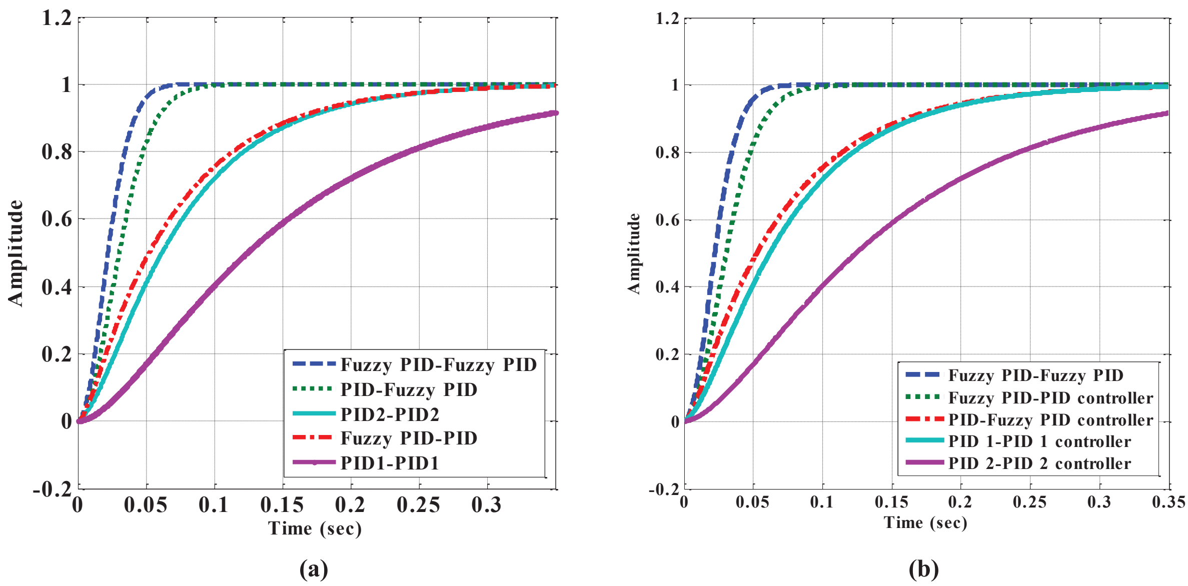


Figure 11. (a) The step response of the azimuth/elevation loop under Algorithm 1; (b) the step response of the azimuth/elevation loop under Algorithm 2

TABLE 2. Transient response analysis results of the azimuth loop

Name	Rise 1 (sec)	Ov 1 (%)	Rise 2 (sec)	Ov 2 (%)
Fuzzy PID-Fuzzy PID	0.07	0	0.08	0
PID-Fuzzy PID	0.10	0	0.15	0
PID2-PID2	0.33	0	0.35	0
Fuzzy PID-PID	0.32	0	0.34	0
PID1-PID1	0.50	0	0.70	0

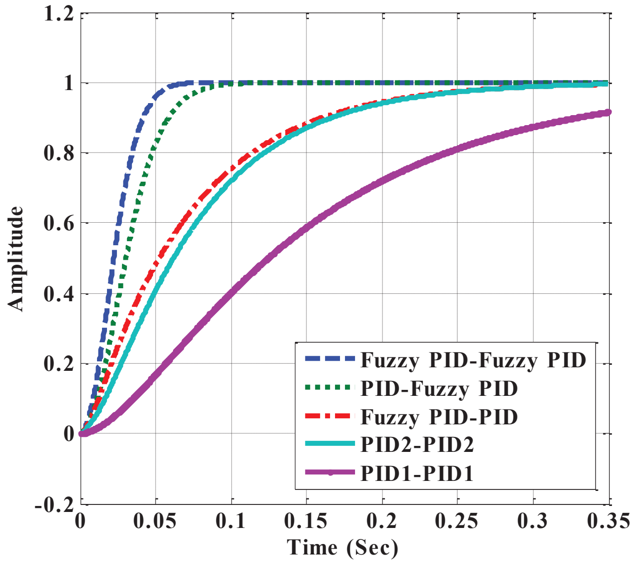


FIGURE 12. The step response of the azimuth/elevation loop under Algorithm 2

TABLE 3. Transient response analysis results of the azimuth/elevation loop

Name	Rise (sec)	Overshoot (%)
Fuzzy PID-PID	0.08	0
PID-Fuzzy PID	0.10	0
PID2-PID2	0.34	0
Fuzzy PID-PID	0.33	0
PID1-PID1	0.52	0

which has better performance than others, there is not over-shooting, and the setting time is the least. The parameters of model 2 are shown in of Table 1. The details are shown in Table 3.

- Test 3: The control algorithm of azimuth/elevation loop under the parameter of motor model 3

The step response of the elevation loop is shown in Figure 13, Fuzzy PID-PID denotes tracking controller is fuzzy PID controller and stabilization controller is PID controller, which has better performance than others, there is not over-shooting, and the setting time is the least. The parameters of model 3 are shown in of Table 1. The details are shown in Table 4.

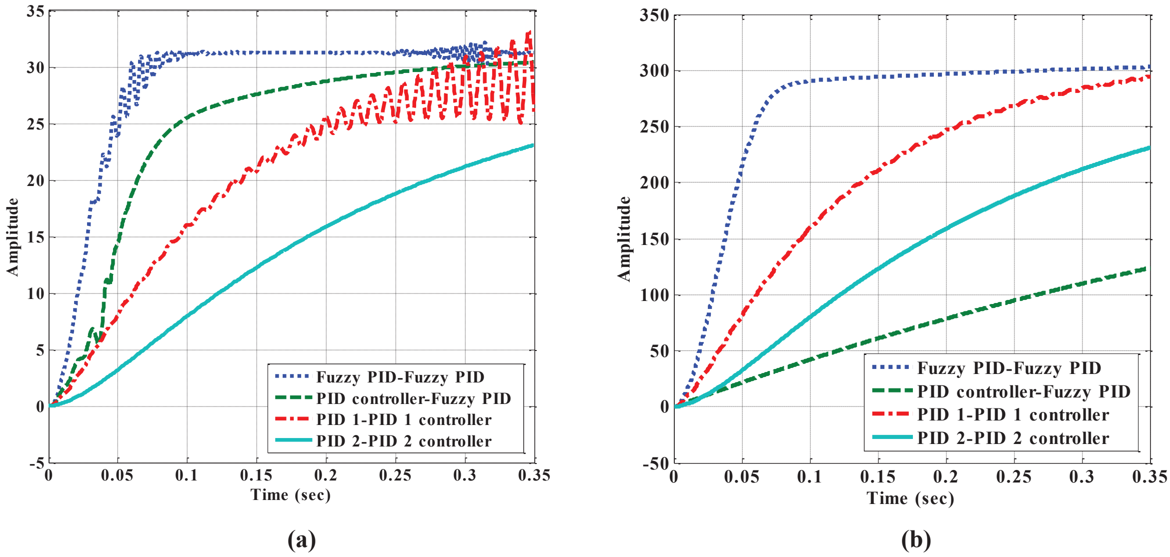


FIGURE 13. (a) The step response of the azimuth/elevation loop under Algorithm 1; (b) the step response of the azimuth/elevation loop under Algorithm 2

TABLE 4. Transient response analysis results of the azimuth/elevation loop

Name	Rise 1 (sec)	Ov 1 (%)	Rise 2 (sec)	Ov 2 (%)
Fuzzy PID-PID	0.12	0	0.10	0
PID-Fuzzy PID	0.30	0	0.35	0
PID2-PID2	0.34	0	0.40	0
PID1-PID1	0.70	0.2	0.68	0

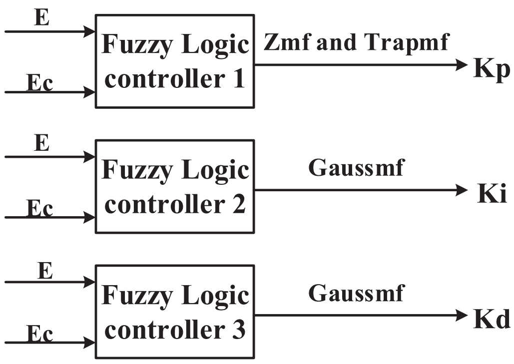


FIGURE 14. The best matched

- Test 4: The best combination

In Figure 14, the best combination is established according to the above simulation results, which can elevate the tracking performance of the overall system.

7. Conclusions.

(1) The fuzzy PID control algorithm is proposed to optimize the performance of control system and enhance tracking ability. Proposed control algorithm is different from ordinary algorithm, in which the types and numbers of MFs about input and output are distinct from each other. The number of the proposed MFs E*EC is 8*7 and 7*6, while ordinary

MFs is 5*5, 7*7 and 9*9 separately; besides, the hybrid types of trimf and trapmf are utilized, which outperforms traditional means. Some simulation results are applied to evaluating the model's performance and investigating the effect of the proposed fuzzy PID control scheme. The results prove that the novel methods have superiority in tracking performance.

(2) The fuzzy PID controller has huge influence on tracking performance of the system. Fuzzy PID of tracking controller has better step response than others, there is not over-shooting, the setting time of fuzzy PID controller-fuzzy PID controller is 0.07s, and the setting time of fuzzy PID controller-PID controller is 0.08s.

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