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Retraction

Retracted: Single-Input Single-Output System with Multiple Time Delay PID Control Methods for UAV Cluster Multiagent Systems

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This article has been retracted by Hindawi following an investigation undertaken by the publisher [1]. This investigation has uncovered evidence of one or more of the following indicators of systematic manipulation of the publication process:

(1) Discrepancies in scope
(2) Discrepancies in the description of the research reported
(3) Discrepancies between the availability of data and the research described
(4) Inappropriate citations
(5) Incoherent, meaningless and/or irrelevant content included in the article
(6) Manipulated or compromised peer review

The presence of these indicators undermines our confidence in the integrity of the article's content and we cannot, therefore, vouch for its reliability. Please note that this notice is intended solely to alert readers that the content of this article is unreliable. We have not investigated whether authors were aware of or involved in the systematic manipulation of the publication process.

Wiley and Hindawi regrets that the usual quality checks did not identify these issues before publication and have since put additional measures in place to safeguard research integrity.

We wish to credit our own Research Integrity and Research Publishing teams and anonymous and named external researchers and research integrity experts for contributing to this investigation.

The corresponding author, as the representative of all authors, has been given the opportunity to register their agreement or disagreement to this retraction. We have kept a record of any response received.

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[1] L. Yan, M. W. Ahmad, M. Jawarneh, M. Shabaz, R. Raffik, and K. H. Kishore, "Single-Input Single-Output System with Multiple Time Delay PID Control Methods for UAV Cluster Multiagent Systems," *Security and Communication Networks*, vol. 2022, Article ID 3935143, 7 pages, 2022.

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Research Article

Single-Input Single-Output System with Multiple Time Delay PID Control Methods for UAV Cluster Multiagent Systems

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Multiagent has become a multidomain intersecting hot issue as artificial intelligence technology has advanced in the industrial sector. Multiagent system creation control has lately undergone a lot of academic research, and it has got applications in a wide range of fields, including drag reduction, monitoring, telecommunications relay, and searching. A matrix theory using algebraic graph theory for automatic control principle learning is proposed based on multiagent system collaborative control strategy method to study the application of PID control method in human-machine cluster multi-intelligence system. The method first presents the determination of the stability set of the low-order controller parameters for the multidelay single-input single-output system with complex coefficients; through matrix theory, the multi-intelligence system is decomposed into multiple subsystems and the problem is transformed into subsystem stability analysis problem; thus, the complexity of the system is reduced. It has been proved that the power system device adopted by the UAV hardware platform can make the UAV flight time up to 24.7 min and additional load up to 1.5 kg. Based on the simulation analysis of PID control algorithm, the PID parameters of UAV are adjusted, which improves the parameter tuning efficiency and enhances the response speed of UAV to error and the stability of motion. The experimental findings suggest that the UAV hardware platform in the UAV control system has high dynamic performance. Good PID settings allow the UAV to respond to control orders quickly and correctly; also, the data received by the sensor decrease the complexity of operating several UAVs at the same time and minimize the operators' burden.

1. Introduction

With the rapid development of computer technology, artificial intelligence technology, and automatic control technology in the industrial field, multiagent has grown into a multidomain intersection hot topic. Multiagent is a hot research direction in artificial intelligence research, and there are many control methods for it [1]. Formation control of multiagent systems has aroused a lot of academic attention recently, and it has found applications in a wide variety of disciplines, including drag reduction source, monitoring, telecommunications relay, and seeking [2, 3]. Among the many methods, the famous scholar Murray has described in detail the various control methods of multiagent system and the application prospect of multiagent system is also imagined. In the current study, the parameter stable set of the low-order controller based on the collaborative control method has not been solved well; therefore, the multiagent cooperative control method based on low-order controller is mainly studied. In collaborative control, the multiagent system is composed of several multidelay single-input and single-output subsystems with complex coefficients, and the stability of the subsystems is the basis for the study of collaborative control [4]. With the advancement of single unmanned aerial vehicle (UAV) technology, he predicted a growing need for several UAVs to collaborate on tasks, particularly difficult ones like finding a UAV's optimal configuration. Control engineering and robotics specialists have been debating the utility of these algorithms in multi-UAV systems [5, 6]. As a result, for multidelay systems with complex coefficients, the stability set of low-order controller parameters is investigated. The solution of the P controller stable set for stabilising multidelay systems is suggested based on the expanded application of Nyquist in pseudo-polynomial, and it is also extended to solve the stable set of PI controller and PID controller. Deep learning is a machine learning and artificial intelligence (AI) technique that mimics how people acquire knowledge. Data science, which also encompasses statistics and predictive modelling, contains deep learning. Deep learning employs massive neural networks with several layers of processing units to learn complicated patterns in vast volumes of data, taking the use of increase in computer power and improved training procedures. Image and voice recognition are two common uses.

Then, the method of solving the parameter set of the distributed controller of the multiagent system is described based on the method of solving the stable set of the subsystem low-order controller. The cooperative control problem of multiagent systems is transformed into the stability analysis problem of multiagent systems [7]. Through matrix theory, the multi-intelligence system is decomposed into multiple subsystems and the problem is transformed into the stability analysis problem of subsystems, thus reducing the complexity of the system. The stability range of the multiagent system is determined by solving the intersection of the stability range of subsystems. Murray, a well-known academic, has detailed in depth the numerous control techniques of multiagent systems, as well as the multiagent system's application prospects. The multiagent system in collaborative control is made up of numerous multidelay single-input and single-output components with variable coefficients, and the durability of the components is the foundation for collaborative control research. The multiagent system's instability range is found by solving the junction of subsystem stability ranges. However, when the subsystem is unstable, the distributed cooperative control method is no longer applicable [8]. To the best of our knowledge, there is no control of second-order effects in time-varying formation tracking. The issue of multiagent systems with switching topologies remains unresolved. Consensus tracking concerns and formation tracking issues for multiagent systems with fixed or fixed-integrator switching topologies were explored despite being time-invariant [9, 10]. Based on the distributed cooperative control method, a method for solving the parameter stable set of two degrees of freedom controller is proposed. Finally, the effectiveness of the cooperative control method is demonstrated by its application to wheeled robots. The algorithm provides an accurate stable range of controller parameters, so that parameters can be conveniently selected to adjust the performance of the multiagent system, improving the efficiency and reducing the cost [11]. Artificial intelligence (AI) is the foundation for simulating human intelligence activities by developing and deploying algorithms in a flexible computing environment. Broadly said, AI aims to make computers think and behave like humans. Intelligent programmes can spot patterns in large amounts of data collected by a factory, which may then be utilized to improve production processes and minimize energy use.

For more than 20 years, scientists have been researching formation control, and several classic formation control methods, such as leader-follower, virtual structure, and behavior-based ones, have been proposed [12, 13]. Zhou et al. proposed a cooperative control method based on the induced course, which can realize formation control, group obstacle avoidance, and other functions [14]. Wang et al. proposed a method combining the pilot algorithm, virtual structure method, and behavior-based method, greatly improving the reliability of communication between UAVs. A UAV cluster search framework integrated with anti-Flocking algorithm is proposed, and the algorithm has realized a distributed and intelligent control mechanism, which is well adapted to the dynamic environment [15]. The virtual structure method ensures correctness of the formation shape but does not allow for flexible transformation. A definite link exists between robots in formation in the leader–follower architecture. The behavior-based method combines numerous goal-oriented behaviors at the same time, allowing them to navigate to waypoints, avoid dangers, and maintain formation all at the same time. The primary focus of this research is a squad of robotic vehicles that the US Army plans to deploy as a reconnaissance unit. Monot et al. proposed a consistency algorithm based on multiagent. Compared with the above methods, this algorithm has the characteristics of noncentralized and completely autonomous UAV cluster [16]. Although several research have been done on the formation control and obstacle avoidance of multi-UAV systems [17, 18], only a few have looked at the movement. A distributed connectivity-preserving and collision-avoidance USV formation tracking issue was explored with constrained communication ranges [19]. For smart agricultural unmanned aerial vehicles, Kumar et al. [20] presented the Secured Privacy-Preserving Framework (SP2F) (UAVs). After considerable research and comparison, they believe that the SP2F framework outperforms several state-of-the-art approaches in both non-blockchain and blockchain scenarios. Balamurugan et al. [21] recommended that a low-complexity solution for tracking drone DOA be developed. The simulation results show that the proposed DOA tracking technique takes less time than standard DOA estimation methods to follow the current location of the drone target. The network's amazing openness, though, will offer new obstacles.

Significant progress has been made in multiagent consensus control during the previous five years, with numerous results. Consensus approaches were expanded in order to deal with second-order multiagent system formation control issues [22, 23]. A cooperative control method based on multiagent systems is presented using learning matrix theory, algebraic graph theory, and automated control principles. The research of cooperative control has revealed that the implementation of cooperative control requires the steady functioning of all agents. Of course, the goal is to design a control strategy that can meet the requirements of the industrial site, and because time delays are unavoidable and varied in the real world, a collaborative control method based on low-order controllers is proposed for the multiagent system with complex coefficient multidelay model subsystem in the industrial field [24]. It should be noted which only formed stability difficulties for multi-UAV systems were addressed in forming the proper time-varying formed, and the complete configuration may also need to watch the virtual/real leader's trajectory to perform the responsibilities [25, 26].

2. Multi-Intelligent Systems

The cooperative control method of multiagent system is the cornerstone of multiagent system research. The distributed control method is an important branch of multiagent cooperative control method. The multiagent system is composed of several single-input and single-output subsystems, and the purpose of distributed control is to achieve cooperative control through the controller applied to each subsystem and the communication and coordination among subsystems. In the control field of a general multiagent system, centralized control and distributed control are two common methods:

2.1. Centralized Control Method. Centralized control, as the name implies, consists of a central master server that centrally controls many underlying actuators; a schematic diagram is shown in Figure 1. Similar to the control over a single individual, the central server will have direct control over the underlying actuators. In this control structure, information is centrally processed and redistributed on a central server; this means that the central server needs to have fast computing ability, information collection ability, and global control ability [27]. Many scholars at home and abroad have proposed excellent centralized control algorithms; through the analysis of these algorithms, the advantages of centralized control can be summarized as follows:

(a) The high concentration of information resources makes management more convenient and standardized
(b) High utilization of information
(c) Easy execution of system commands
(d) Be able to focus on strengths and improve work efficiency

While centralized control can analyze, plan, decide, solve, and optimize problems from a global perspective, its practical application still has some defects that cannot be ignored:

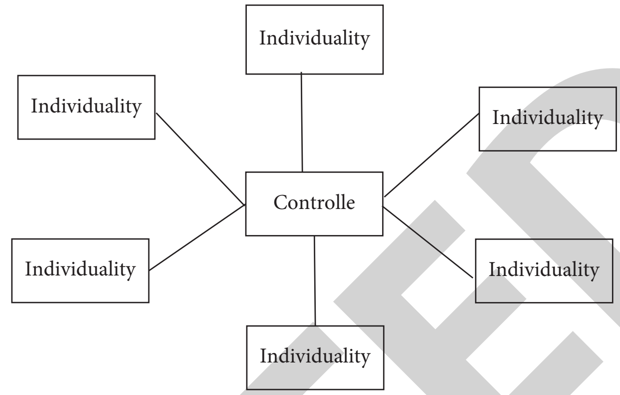

Figure 1: Schematic diagram of the centralized control structure.

(a) With the continuous expansion of scale and the improvement of functions, the complexity of the system increases exponentially, which brings great trouble to management and maintenance.
(b) Poor adaptability, unable to timely deal with sudden events, results in huge losses.
(c) The system is fragile. When the main controller fails, it will be paralyzed and unable to operate.
(d) The cost of building and managing and maintaining a high-performance machine is enormous.

2.2. Distributed Control Method. Compared with centralized control methods, distributed control methods no longer pursue centralized control and this frees servers from increasingly complex structures and high maintenance costs. Distributed control means that there are multiple agents with autonomous capabilities, which are independent of each other, through information interaction with neighbors. Figure 2 is a typical example of distributed control in which resources are reallocated and collaborate to achieve global goals. A distributed control system (DCS) is a digital control system for a business or plant with several control loops in which independent controllers are spread across the system with no central operator supervisory control. This differs from systems that rely on centralized controllers, such as discrete controllers housed in a central control room or within a central computer. By locating controls close to the process plant and allowing for remote monitoring and supervision, the DCS approach improves dependability and lowers infrastructure costs.

The multiagent cooperative control approach includes a branch decision control. The multiagent system is made up of numerous single-input single-output subsystems, and the goal of distributed control is to accomplish collaborative control by using a controller for each subsystem as well as collaboration and cooperation between them. Input is effectively processed and distributed on a central server in a control structure, which means that the central server must have rapid computing, information collecting, and global control capabilities. Distributed control refers to the presence of several autonomous agents that are independent of

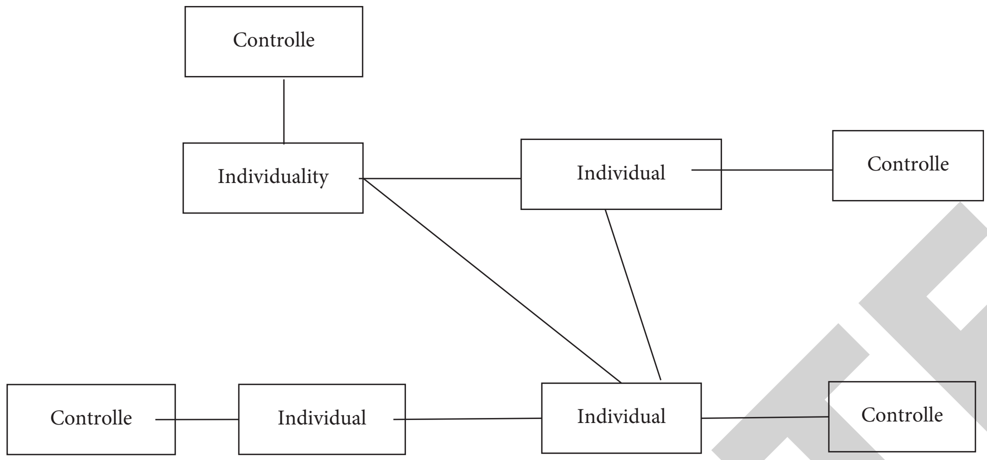

Figure 2: Distributed control system.

one another, thanks to information exchange with neighbors.

In multiagent network, the data interaction between nodes can be summarized by algebraic graph theory. Therefore, algebraic graph theory is the basis of multiagent system research. The directed graph $G = \{V, \varepsilon, A\}$ is used to represent the communication relationship between each node, $V = \{V_1, V_2, V_3, \cdots V_n\}$ indicates the collection of each node. And, the weighted adjacencies matrix of the directed graph G of $A = [a_{ij}] \in R^{n\times n}$; its nonzero adjacent nodes are denoted by a_{ij}. Suppose $e_{ij} = (V_i, V_j)$ represents the edge connecting two adjacent nodes of the directed graph G. Define two nodes connected by edges in a directed graph to have a positive value, that is, $e_{ij} \in \varepsilon \Leftrightarrow a_{ij} \rangle 0$. Let $a_{ij} = 0$; the neighbor of node 1 be defined as $N_j = \{j \in V | a_{ij} = 0\}$. d_i is used to define the radix N_j, which represents the degree of agent I [28]. Therefore, the general Laplacian matrix of the directed graph G can be defined as $L = D^{-1}(D - A)$, where $D = \mathrm{diag}(d_1, d_2, \cdots d_n)$, from which the following equation can be obtained:

$$L_{ij} = \left\{ \begin{array}{ll} 1, & \text{if} \quad i = j \\ -\dfrac{1}{d}, & \text{if} \quad j \in N_i \\ 0, & \text{if} \quad j \notin N_i \end{array} \right\}. \qquad (1)$$

Not all matrices are diagonalizable. The Laplace matrix L can be diagonalized if and only if the directed graph G is connected. Therefore, the research of multiagent cooperative control system is based on the connection of directed graph G. For a given $N \times N$ matrix Q, define the matrix Q_k of $N_k \times N_k$ as follows:

$$Q_{(k)} = Q \otimes I_k, \qquad (2)$$

where $\otimes$ represents the Kronecker product.

2.3. PID Control Algorithm. Proportional gain of PID controller k_p: the range solution of integral gain k_i and differential gain k_d is extended on the basis of P controller and PI controller. The closed-loop characteristic equation of the multidelay system with PID controller is

$$\delta\left(s, k_p, k_i, k_d\right) = sU(s) + \left(k_p s^2 + k_p s + k_i\right) V(s). \qquad (3)$$

Multiply (3) by $v(-s)$ and set $s = j\omega$ to get

$$\delta'\left(j\omega, k_p, k_i, k_d\right) = \delta\left(s, k_p, k_i, k_d\right) V(-S), \qquad (4)$$

where $q(\omega, k_p)$ is as shown in

$$p\left(\omega, k_i, k_p\right) = p_1(\omega) + \left(k_i - \omega^2 k_d\right)\left[V^2(\omega)\right]. \qquad (5)$$

For a given multidelay system with PID controller, if k_p is given, at least one $I = \{i_0, i_1, \cdots\}$ satisfies formula (4) and the stable range of (k_d, k_i) can be given by the inequality group:

$$[k_i - A(\omega_1)K_d + B(\omega_1)] i_1 \rangle 0. \qquad (6)$$

Considering the following multidelay system, the stability control algorithm is used to calculate the low-order stability controller, as shown in

$$G(s) = -\frac{0.3534}{.5.235s^2 + 16.11s + 1} e^{-3.14S} - \frac{0.5519}{42.2.25s^2 + 19.1s + 1} \cdot e^{-2.345s}. \qquad (7)$$

According to the above, (8) can be obtained:

$$U(s) = (13.5s + 1)(2.61s + 1)(16.55s + 1)(2.55s + 1). \qquad (8)$$

Next, the stable range of proportional gain k_p is obtained: calculate the $-1/G(j\omega_1)$ corresponding to each i_1, when $i_0, i_2, i_4, i_6, i_8, i_{10}$. The corresponding $-1/G(j\omega_1)$ values were 0.9, 1.26, 3.37, 4.7, 6.91, and 9.17, respectively. The corresponding value of $i_1, i_3, i_5, i_7, i_9, i_{11}$ is −6.9, −322.5, −7517, −1777.5, −2295, and −6393. Therefore, the stable range of gas is $\{k_p | k_p \in (-6.9, 0.9)\}$; in order to prove the correctness of the stability region, each point $k_p = -6.5$ in the range, a point $k_p = -6.9$ above the boundary, and a point

$k_p = -7.5$ outside the range verify the closed-loop step response of a system with multiple delays, as shown in Figure 3, as the value of k_p goes from within the range to outside the range; the closed-loop step response in the east and west also experienced a process from stable to constant amplitude oscillation and then to divergence; thus, the correctness of the stable range of k_p is verified.

The stability control of the system is the basis of the cooperative control, and all the cooperative controls are designed on the basis of the stability control. A stability control algorithm for multidelay systems based on low-order controllers is proposed. The parameter sets of all low-order controllers are generalized from the standard Nyquist. According to the simulation results, the control parameters selected from the results can ensure the stable operation of the system. The proposed stability algorithm for multidelay systems avoids the time delay approximation and thus greatly increases the accuracy of the stability range. For the systems with multiple time delays, the results can be applied to the satisfactory control strategy and the optimal control strategy. This technology is particularly promising for practical use, given the frequency of time delays and the prevalence of low-order controllers in the industrial sphere. In the industrial area, computer technology, artificial intelligence, and autonomous control technology are rapidly developing. Because time delays are unavoidable and diverse in the real world, the objective is to build a control strategy that can match the needs of the industrial site.

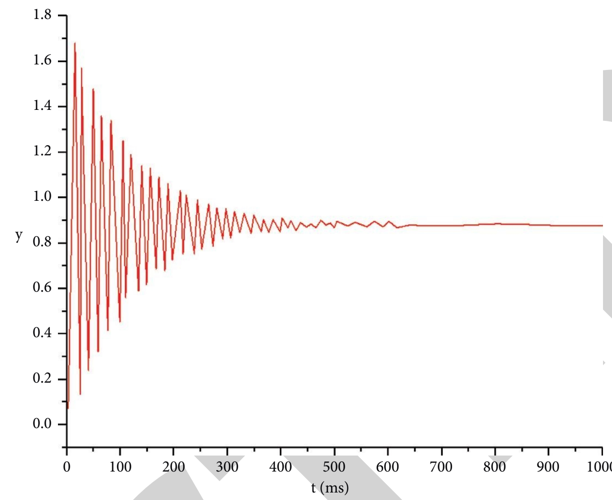

Figure 3: Step response curves under different (k_p, k_d, k_i) values.

Table 1: Hardware parameters of fixed-point casting experiment.

Name	Parameter
Electrical machinery	580 KV
Propeller	1255
Electric adjustment	30 A
Wheel base	500 mm
Cell	4S–5300 mAh
Drojecter	13 kg
Difference GPS	5 cm

3. Experimental Analysis

The overall performance of the UAV hardware platform is comprehensively tested by the UAV fixed-point throwing experiment, for example, flight time and sensor accuracy. Table 1 shows the UAV hardware parameters adopted in the fixed-point throwing experiment. The UAV fixed-point hurling experiment thoroughly tests the overall efficiency of the UAV hardware platform. Unmanned aerial vehicle (UAV) flight tests are conducted without load, and data such as flight time, flight speed, and flight distance are collected.

Next, the experimental procedures and experimental results are introduced and analyzed in detail.

3.1. Operation Procedure

(1) Two throwers are, respectively, installed in the front and rear of the UAV, and the signal line of the throwers is connected to the MAIN OUT port of the flight control system.

(2) Use ground control software to identify the UAV's flying point, PWM wave of precise frequency, while the flight control is programmed to output to the throwing gear steering gear at the defined location to control the cargo dropping. Once the setting is complete, the flight mission is uploaded to the drone.

(3) Flight test is carried out in the case of unmanned aerial vehicle (UAV) without load, and data such as flight time, flight speed, and flight distance are recorded.

(4) The load and sensor accuracy test is carried out, and remote control is used to control the UAV to take off to an altitude of five meters; after the flight mode is switched to mission mode, the drone begins to fly according to the point mission and drops the cargo at the designated location; the accuracy of UAV flight can be judged by the location of cargo landing.

(5) The cargo weight is gradually increased, the change of UAV flying attitude is observed, and its load capacity is recorded.

4. Discussion

In recent years, swarm obstacle avoidance has become an important direction in the research field of UAV cluster. Only by solving the problem of UAV safe obstacle avoidance can UAV cluster successfully complete its flight mission. UAV swarm obstacle avoidance requires that the drones in the cluster can cooperate with each other without interfering with each other; in addition, they can cooperate with each other to avoid obstacles in low altitude (such as static obstacles such as buildings and trees). The commonly used obstacle avoidance algorithms include ultrasonic obstacle avoidance, lidar obstacle avoidance control, artificial potential field, and artificial neural network obstacle avoidance.

Table 2: UAV performance parameter table.

Name	Parameter
Flight time	24.7 min
Remaining payload	1.5 kg
Maximum tilt angle	64.4°
Maximum tilt angle	17.9 m/s
One-way flight distance	15.26 km
Droitching accuracy	10 cm

This time, the ultrasonic obstacle avoidance control method is adopted to solve the problem of UAV cluster avoiding static obstacles. The UAV sends sound waves to the front of the movement and monitors the returned sound waves; the measured distance between the UAV and the obstacle determines its motion state:

(1) After the ultrasonic obstacle avoidance module, ad hoc network communication module and autonomous motion control module are designed and built and the single machine test is conducted to ensure that the single machine has no problems.

(2) The artificial potential field algorithm, the pilot algorithm, and the ultrasonic obstacle avoidance algorithm were transplanted into the algorithm execution module of the cooperative computer. In order to ensure flight safety, the artificial potential field algorithm sets the safe distance between uAVs in the cluster as 3 m and the maximum flight speed as Sm/s; at the same time, the coordinate of the pilot is set as (0, 0), and the position coordinates of other UAVs are obtained by calculating the relative position with the pilot.

(3) After connecting the UAV through the IP configuration area of the ground control software, it plans the UAV's flight path, sets the target flying point, and places obstacles on the UAV'S flight path.

(4) The cluster control function of the ground control software is used to control the simultaneous take-off of the UAV, and the electronic map is used to observe whether the display information of the UAV position is accurate; then, the flight mode of the 8 UAVs is switched to the mission mode at the same time, and the UAVs begin to fly according to the algorithm and the flight path task.

The experimental results show that the UAV hardware platform has good dynamic performance in the UAV control system as shown in Table 2; at the same time, good PID parameters enable the UAV to respond to control commands quickly and accurately; moreover, the data collected by the sensor reduces the complexity of operating multiple UAvs simultaneously and significantly reduces operator workload. The route is basically reliable after being limited and filtered by the computer. The cluster control function reduces planning function can set up the point mission of UAV in the cluster in advance. The 3D virtual scene is a showpiece for no one and the relative altar. The actual rider's practical analysis of the algorithm is presented.

5. Conclusions

To begin with, a technique for solving the parameter stability area of a low-order controller for single-input single-output systems with multiple delays and complex coefficients is provided, because the stability of each agent is a precondition for multiagent systems to achieve cooperative control. Based on the stable realization of single-input single-output system with multiple time delays, the distributed cooperative control method of multiagent is proposed and many distributed cooperative control systems are studied on the basis of individual stability. Finally, based on the wheeled robot physics experiment system, the collaborative control research is carried out, and the algorithm is combined with practice to verify the feasibility and effectiveness of the algorithm. It has been verified that the power system device adopted by the UAV hardware platform can make the flight time of UAV up to 24.7 min and the extra load up to 1.5 kg, etc. Based on the simulation analysis of PID control algorithm, the PID parameters of UAV are adjusted, which improves the parameter tuning efficiency and enhances the response speed of UAV to error and the stability of motion.

The formation control algorithm of a multi-UAV system, as well as the challenge of contoured obstacle avoidance, will be researched in the future. The method, which combines the virtual structure and artificial potential field, can efficiently organize UAVs to produce the appropriate creation and vary the shape of the formation via pattern switching and scaling procedures.

Data Availability

Data are available from the corresponding author upon request.

Conflicts of Interest

The authors declare no conflicts of interest.

Acknowledgments

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