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# PD Control-based Simulation Analysis of a DC Motor for UAV Applications

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**Abstract:**

Unmanned aerial vehicles (UAVs) have played many roles in various fields in recent years, such as agriculture, industrial surveying, aerial photography, etc., and have become a hot topic in production and people's daily lives. The motor of the UAV is one of the key components of the UAV's dynamic system, taking an irreplaceable position in the UAV's flying progress. UAV uses small alternating current (AC) motors to drive propellers and provide lift, helping the whole UAV system complete various actions in the air, enabling the flying device to finish tasks according to people's expectations. Therefore, researching AC motors in the case of drone applications is greatly significant. This article explains the principle of direct current (DC) control circuits and various systems of drones at first and analyzes the advantages of applying DC control circuits to drone motors. Finally, by adjusting the parameters of the DC control circuit, the article checks the output effect of the control circuit under the background of the drone application. Experiments have shown that DC circuits with the advantages of fast feedback and minimal oscillation avoidance are suitable for the use of UAVs and can improve their maneuverability.

**Keywords:** PD control; DC motor; UAV

## 1. Introduction

With the development of science and technology, people's special need for convenience in work and life is also increasing. Various stakeholders and actors, including governmental authorities, commercial operators, scientific institutions, and individuals, make use of UAVs as an affordable data acquisition tool: they enable mapping at temporal and spatial scales that remain unachievable for traditional remote sensing platforms [1]. Some photography enthusiasts have also found the role of UAVs in improving the quality and creativity of their works. The UAV is particularly useful when jobs should be done in places where human lives would be in danger [2].

From a societal perspective, the UAV can also help collect data that scientists need, to assist in building various aspects of big data networks to improve the convenience of people's lives and reduce social operating costs [3]. The motor serves as a pivotal device that transforms electrical energy into mechanical energy generating a rotating electromagnetic field through the stator's windings, which subsequently interacts with the rotor to create a magneto-electric rotational torque, facilitating the motor's movement [4]. A motor comprises two main parts: the stator and the rotor. The fundamental operating principle relies on the interaction between a magnetic field and an electric current flowing through the rotor, resulting in the rotation of the motor [5]. At the heart of this energy conversion process lies the rotor, which is instrumental in realizing the transformation from electrical to mechanical energy. The input of the signal must be stable to make the actions of the UAV accurate and rapid.

No matter what purpose it is used for, the UAV carries various sensors, such as detectors, cameras, etc., to provide stable output signals for motors, which helps to improve the credibility of collected data and enhance the quality of the result of UAV operation [6].

Therefore, this article first introduces the basic principles of the PD controller and analyzes the features of this kind of control. In the context of applications of UAV where fast response and stable output are required, the PD control shows great performance. A DC motor, as a key component for executing user instructions, needs the signal to be transferred appropriately after the possessing of the circuit in the UAV system. Therefore, the behavior of drones in the air can be controlled easily. Longitudinal stability of the UAV ensures balance in every situation that moves aircraft from the trim position increasing the UAV's Anti-interference ability to the environment [7].

Though with the help of PD control, the signal could be useful and quick, with parameters of the circuit that are not set well, the signal output could appear to be unstable, or the response could be too slow. Thus, the actions of the UAV in the air are not easy to control. This article also tests different sets of resistors and capacitors to check for the best parameters relatively, making the PD control in the application in UAV efficient.

# 2. Methodology

## 2.1 Basic Principles of the PD Controller

The PD controller combines proportional control and derivative control and takes advantage of the two methods of control.

In proportional control, the signal is resized proportionally by proportional gain (Kp). The mathematical relationship between the input signal and the output signal is represented by this formula.

$$U_{out} = -Kp * U_{in} \quad (1)$$

$$K_p = \frac{R_{out}}{R_{in}} \quad (2)$$

where $U_{in}$ denotes the input voltage and $U_{out}$ denotes the output voltage. $R_{in}$ and $R_{out}$ denote the two feedback resistors' resistance.

The derivative control is sensible to the change of the input signal with the element of the capacitor. The signal is defined by the product of resistance and capacitance, and the differential of input voltage over time. The formula describes the relationship:

$$U_{out} = -K_d * \frac{dU_{in}}{dt} \quad (3)$$

$$K_d = R * C \quad (4)$$

where $C$ denotes the capacitance. $R$ denotes the feedback resistor.

The PD control combines the proportional control and the derivative control, making the output defined by both Kp and Kd. It achieves the result that making the output signal change according to the expectations within one step. The following formula shows the relationship between output voltage and input voltage in PD control reflecting the diverse functions of PD control.

$$V_{out} = -(Kp * Vin - Kd * \frac{dU_{in}}{dt}) \quad (5)$$

where $dt$ denotes differentiation of time.

The combination also helps the system better bind the characteristics of both.

Because of its simple form and popularity among engineers, PD control has been widely used in many industrial applications such as robotic control, process control, and automatic control [8].

## 2.2 The features of the PD controller

Because of its ability to reduce the oscillation, in the derivative control, the system shows the advantage of stability. Yet the steady error is not solved in this kind of control. The proportional control can reduce the steady error by changing its Kp. It also is widely used for its capability to quickly respond to input signals. When Kp is too high, the stability of the system becomes lower. The PD controller combines the advantages of both and achieves the balance of stability, quick response, and reduced steady error. It solves the problem of the slope of error, and it is valid in the transient response [9]. These advantages make PD control more suitable for practical applications that require a balance between fast response and stable output, as well as anti-interference. For example, the PD control with compensation presents positive results to avoid high derivative gains and identify uncertainties that occur in the real operation of robot manipulators [10].

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# 3. Results and Discussions

## 3.1 UAV Control System Design

### 3.1.1 Consideration of UAV usage

A UAV is a flying device that is able to fly along predetermined routes or be controlled in real-time by humans. To control a UAV does not require a professional pilot. A UAV has excellent endurance and can stay in the air for dozens of hours. It can perform a scan of the region that is both accurate and continuous [11]. It can also work in foggy weather and at night.

Nowadays, there are many different existing types of drones. The main drone types are fixed-wing systems and multirotor systems and there are also some other kinds of drones that cannot be defined as fixed-wing systems or multirotor systems like ornithopters and drones with jet engines [1].

A UAV consists of several components, which include a dynamic system, remote control system, flight control system, and airborne equipment. The dynamic system provides the necessary power for flight. The remote-control system is used by a user to control the UAV, sending commands to the UAV. The flight control system includes sensors like a gyroscope, accelerometer, angular velocity meter, etc. The airborne equipment varies with different use demands. For example, a radar could be equipped for collecting geographic data.

An electric motor is a device that converts electrical energy into mechanical energy. The motor plays a crucial role in the flight of drones. According to the classification of power sources, electric motors can be divided into DC motors and AC motors. Due to the relatively lower voltage and power requirements of drones, they use DC motors, so this article primarily discusses the control circuit of DC motors in the context of drone applications.

The remote-control system helps users send commands to drones, and the drone receives signals, which are processed by circuits and converted into voltage changes to enable the drone to perform specific actions. This article discusses the applicability of PD control circuits in manipulating unmanned aerial vehicles and in situations where unmanned aerial vehicles encounter signal fluctuations.

According to the statements above, the control part of the circuit should have a stable output voltage, a quick response to the command that is sent by the user, and the ability to maintain stability under slight external interference with input voltage.

### 3.1.2 Parameter Determination of PD Controller

In designing PD control circuits, Kd and Kp can directly affect the characteristics of the circuit, so choosing the appropriate Kd and Kp is particularly important. Considering the requirements for the use of the UAV, the required circuit needs to respond quickly, output stably, and avoid oscillation. The setting of Kp affects the response, but an inappropriate Kp can lead to overshoot and instability. The setting of Kd can affect the suppression of response, but a Kd that does not meet the requirements can lead to amplified noise or introduce excessive oscillation. Operational amplifiers, as key circuit components, are used to construct the required circuits. This article uses Falstad software for circuit simulation.

Fig. 1 shows an example of the design of the PD control model circuit.

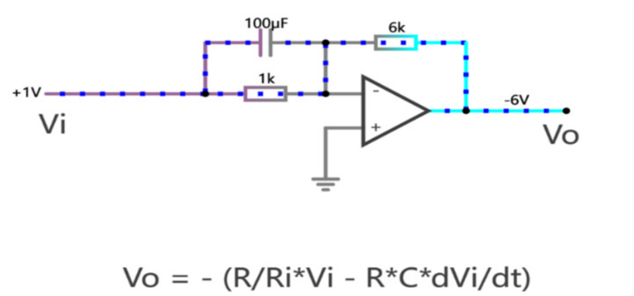



**Fig. 1 PD controller design. (Photo/Picture credit: Original)**

## 3.2 Analysis of The Control Effect of the Designed Control System

### 3.2.1 Control Function Simulation Results

Falstad software helps try different parameters of the PD controller part of the circuit to see which parameter could be the most suitable for the target so that the output is both stable and fast to respond. PD control motor simulation circuit is shown in Fig. 2.

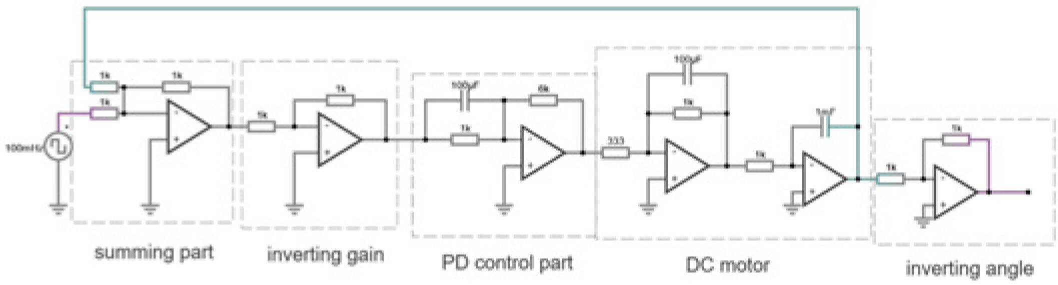
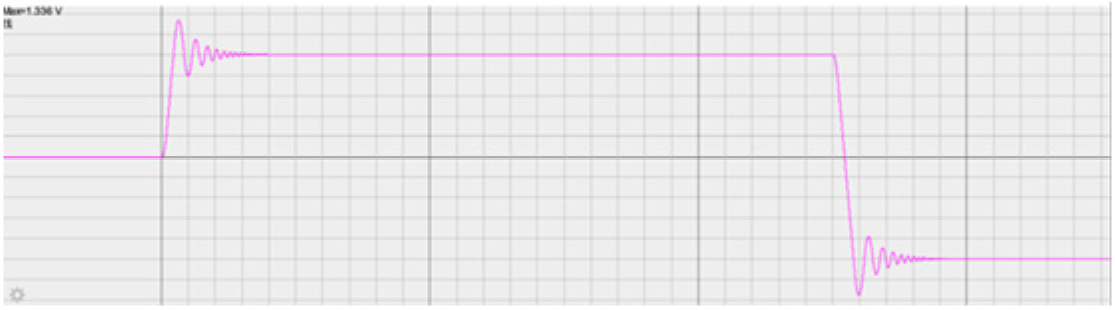
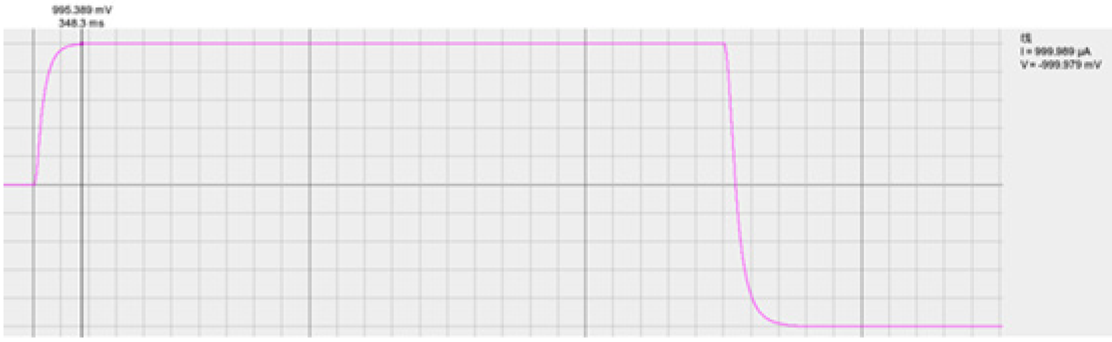



**Fig. 2 PD control motor simulation circuit. (Photo/Picture credit: Original)**

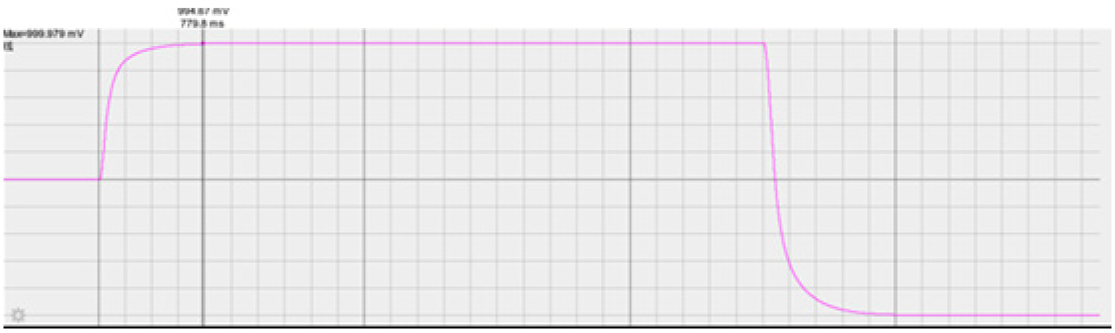
In Fig. 3, different values of Kp's influence on the output voltages are tested, the main focus is the ability to eliminate the oscillation of output voltage and the length of time for the output to become stable. From top to bottom, the values of Kp are 12,6,3,2. And the Kd value is set to be 0.6. The input voltage is a square wave voltage with a peak value of 1 volt.



(a)



(b)



(c)

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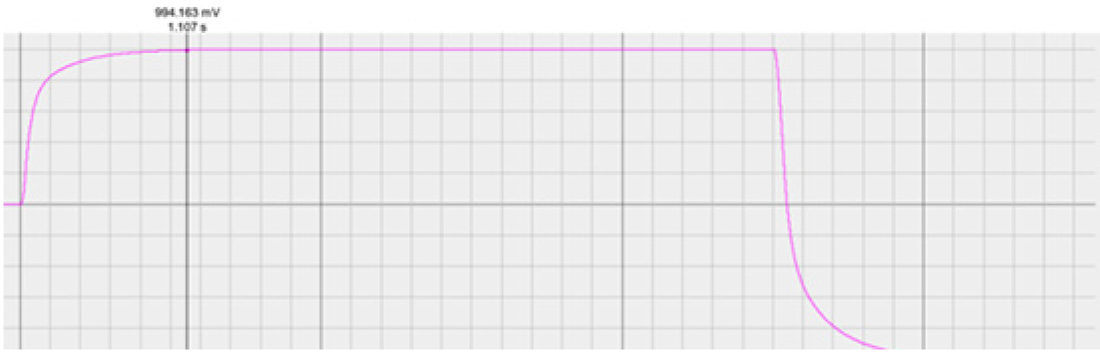
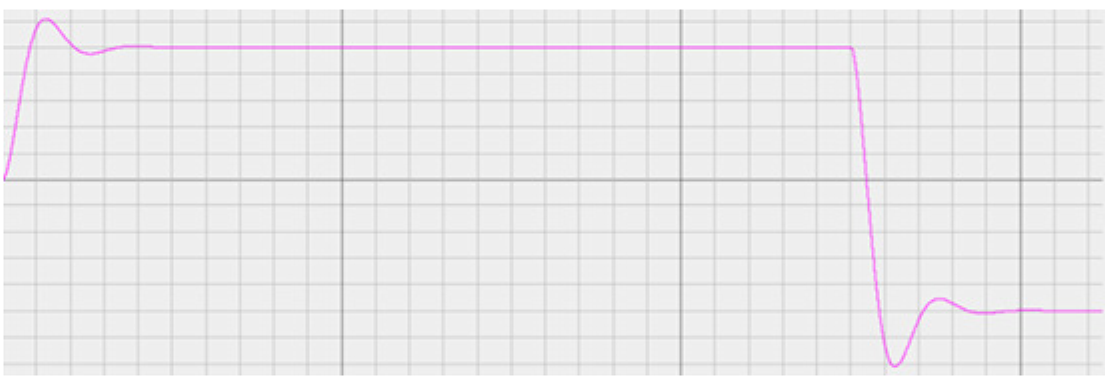



(d)

**Fig. 3 Output with different Kp. (a) Kp is 12, (b) Kp is 6, (c) Kp is 3, (d) Kp is 2. (Photo/Picture credit: Original)**

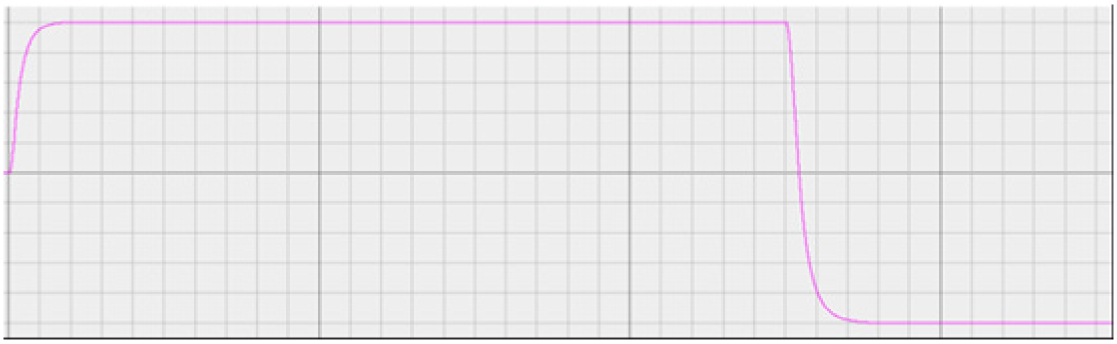
As is shown in Fig. 3, when Kp is too high, the oscillation is too obvious, making the PD controlunsuitable for the goal of making output stable. However, with a Kp of a lower value, it takes too long for the output voltage to get into a stable stage, which is bad for the control of the UAV. So the value of 6 for the Kp is appropriate relatively.

In Fig. 4, the different values of Kd are tested. With a Kp value of 6, values for different outputs of Kd are 0.06,0.3,0.6,1.2.



(a)

(b)



(c)

(d)

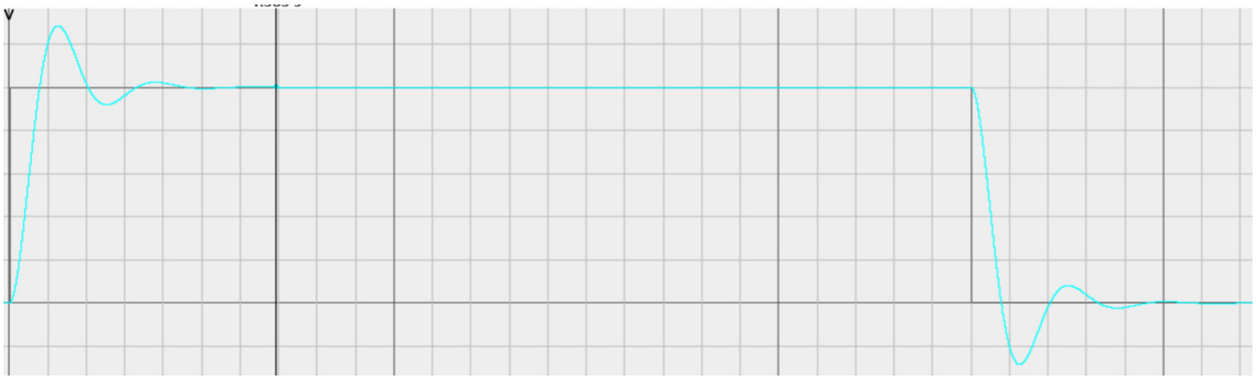
**Fig. 4 Output with different Kd. (a) Output with Kd of 0.06; (b) Output with Kd of 0.3; (c) Output with Kd of 0.6; (d) Output with Kd of 1.2. (Photo/Picture credit: Original)**

As can be seen in Fig. 4, with a value of Kd which is too low, the oscillation makes the voltage's oscillation too big to control the motor. With a value that is too high, the response appears excessively slow, which is not wanted for users who want to make quick decisions when using their devices.

Based on the above test analysis, this article has obtained suitable Kd and Kp values, making the output both fast and stable.

## 3. 2.2 Analysis of the Improved PD controller's advantages

Here the P control and the PD control in the circuit are compared to test the superiority of PD control over P control in response speed and oscillation suppression. With the same value of Kp set as 6, the output is shown in Fig. 5.



(a)

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(b)

**Fig. 5 Output based on P control and PD control. (a) output of P control; (b)output of PD control. (Photo/Picture credit: Original)**

According to Fig. 5, the PD control is significantly superior to the P control in terms of required performance, making PD control more appropriate in the case of controlling the motor of the UAV.

When the input voltage changes because of some special circumstances, the output is shown in Fig. 5 where the input voltage is under the influence of noise whose highest impact is 0.1v.

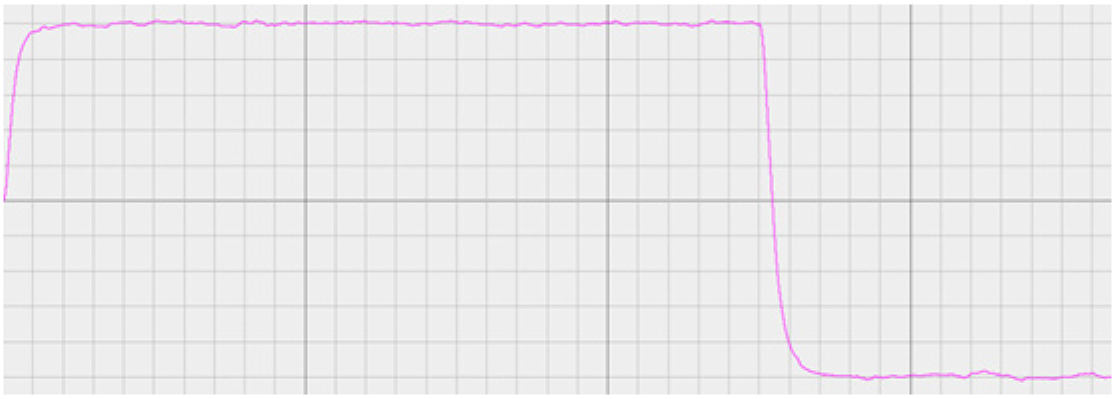

**Fig. 6 Output with noise in an input signal. (Photo/Picture credit: Original)**

As shown in Fig. 6, despite the sudden noise in input voltage, the variation of the output voltage is still stable relatively, so the speed of the motor could not accelerate or decelerate with rapid progress. The circuit can help the device resist to avoid input noise causing loss of control. Due to the robustness of the circuit to interference from input signals, the operation of UAV has greater safety. The device itself is also more durable because of its characteristics.

As mentioned above, the derivative control part of the PD control circuit helps the circuit avoid the oscillation of output, which is crucial for the motor to keep a stable operating speed, making the flying progress more controllable and easier for users. Compared with P control, it takes a shorter time for the output signal to become stable. When dealing with the command sent by the user, the shorter time makes the actions of the UAV more flexible. Because of the derivative control, when the system encounters special circumstances, wind or magnetic field variation, for example, it is still able to keep the voltage for the motor steady so that the UAV's security is guaranteed.

## 4. Conclusion

As part of classical control theory, PD control can still play an important role in the control systems of UAVs. Because of its simple form and reliable feature, PD control can become an essential component of UAV that could be environmentally sensitive and help longer the endurance of the flying device. Due to the stability that PD control provides, UAVs can be used for works with requirements of accuracy of data collected.

By using Falstad software, the article simulates finding the best set of parameters of a PD control circuit and verifies the performance of a PD control circuit in the context of UAVs applications. The results of simulations show that when applicated in UAVs, PD control circuits. The PD control circuit demonstrated satisfactory properties and proved that the PD control circuit can ensure stable and fast electrical signals provided to motor.

In the future development of UAVs, PD control will still be in a high position. PD control can not only be used on motors, but also it can do its part in networks of UAV, helping communication between different devices to be stable and continuous. In this way, large-scale collaboration of multiple drones will become more efficient, and the application fields of drones can become more extensive. The combination of artificial intelligence control for UAV operation will become an important research direction in the future, maybe with the improvement of PD control in UAV applications, the technology will be developed fast.

In conclusion, PD control will continue to play a significant role in the future development of UAV control systems, by possessing a signal, and making the signal transferred into the motor stabilized. The UAV's maneuverability, precision of actions, and operational performance can be increased significantly. With the development of the combination of drone control and artificial intelligence, PD control will provide a greater role in the overall performance of drones.

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