Research on UAV flight attitude control system based on simulink and genetic algorithm

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Abstract. With the evolution of networking and information technology, unmanned aerial vehicles (UAVs) have emerged as integral components in numerous fields, executing diverse and vital tasks. The accuracy and efficiency of UAV operations are greatly influenced by their attitude control systems, which dictate flight stability, speed, and functionality. However, traditional control methods for UAV flight stability and accuracy have become outdated, unable to meet the demands of modern applications. To address these challenges, this study introduces a novel attitude control approach based on genetic algorithms. This method utilizes the principles of natural selection and genetic traits to optimize the parameters of the attitude control system. The objective is to enhance the current control effectiveness, improve the UAV's maneuverability, and enable its versatile applications across multiple fields. Simulink tool simulations are conducted to evaluate the stability of the optimized results. This simulation tool allows for the replication of real-world flight conditions and the assessment of the attitude control system's performance under various scenarios. The results of these simulations provide valuable insights into the effectiveness of the genetic algorithm-based attitude control method. This study contributes to the advancement of UAV technology by improving the accuracy and stability of attitude control systems. It paves the way for more efficient and reliable UAV operations in various fields, from environmental monitoring to search-and-rescue missions, thus enhancing their operational capabilities and expanding their potential applications.

Keywords: Simulink, PID, genetic algorithm, machine learning.

1. Introduction

With the development of science and technology, quadcopter UAVs have been widely used in the fields of aerial photography, reconnaissance tracking, and weather reporting [1, 2]. However, with the complexity and depth of UAV application scenarios and the expansion of UAV market demand, these fields have further requirements for the flight stability and control accuracy of quadcopter UAVs.

Improve the flight attitude control of quadrotor UAV by optimizing the PID controller using genetic algorithm and simulating it through Simulink, so that the UAV can obtain stronger anti-jamming ability, and enhance the stability and control accuracy of UAV flight.

By checking the relevant papers in China's China Knowledge Network, it is found that most of the similar UAV simulation controllers use more traditional PID control algorithms, and do not use such cutting-edge mechanical learning fields as genetic algorithms. Research findings was shown in the Table 1.

Table 1. The results of the research

Thesis title	Optional Controller	use
Research on large bi-rotor UAV based on fuzzy PID	Fuzzy PID	Attitude control of a bi-rotor UAV
MATLAB-based PID simulation design for quadcopter UAV flight control	PID	Attitude control of a quadrotor UAV
Research on Fuzzy Control PID-based Flight Attitude Control Method for Quadrotor UAVs	Fuzzy PID	Attitude control of a quadrotor UAV
CEA-GA based multi-UAV 3D collaborative curvilinear trajectory planning approach	Genetic Algorithm (CEA-GA)	route planning
Genetic Algorithm Based Collaborative Beam Assignment for Unmanned Aerial Vehicles	genetic algorithm	Air fleet coordination

It can be seen that the UAV using genetic algorithm is more used for macro path planning direction, not used for its own attitude control, the control of its own attitude is more traditional control scheme. Genetic algorithms to make UAV flights more stable and to improve control accuracy during flights. Research methodology and process

1.1. UAV power systems

Motion force analysis diagram of a UAV was shown in the Figure 1.

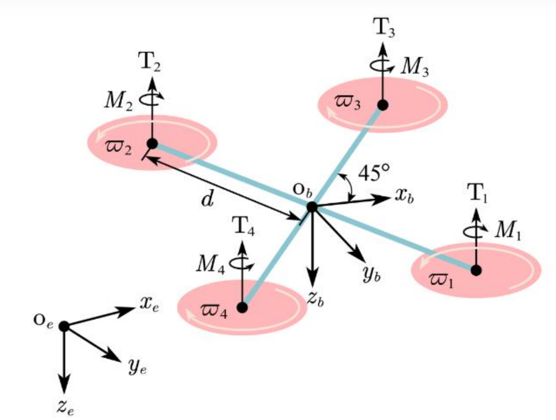

Figure 1. UAV force analysis diagram (photo credited: original)

UAV power system, aiming to explore the UAV kinematics formulae from the physical layer in preparation for the subsequent control system building [3].

Main physical parameters: The basic physical quantity of drone motion was shown in Table 2, and these quantities will be used in subsequent formulas.

Table 2. Key physical parameters of UAV

notation	hidden meaning	unit (of measure)
τp	rolling moment	N*m
τq	pitching moment	N*m
τ_r	yaw moment	N*m
ϕ	roll angle	rad
θ	tilt	rad
ψ	angle of divergence	rad
p	roll rate	rad/s
q	pitch rate	rad/s
r	yaw rate	rad/s
vx	X-direction speed	m/s
Vy	Y-direction speed	m/s
Vz	Z-direction speed	m/s
X	X-direction displacement	m
Y	Y-direction displacement	m
Z	Z-direction displacement	m

The main formula:

$$I_x\dot{p} = (I_y - I_z)\mathrm{qr} + \tau_p \tag{1}$$

$$I_x\dot{q} = (I_z - I_x)\mathrm{pr} + \tau_q \tag{2}$$

$$I_x\dot{r} = (I_x - I_y)\mathrm{pq} + \tau_r \tag{3}$$

$$\dot{\phi} = \mathrm{p} + (\mathrm{r}cos\phi + qsin\phi)tan\theta \tag{4}$$

$$=\mathrm{q}cos\phi\text{-}\mathrm{r}sin\phi \tag{5}$$

$$\dot{\varphi}=\frac{1}{cos\theta}(\mathrm{r}cos\phi+\mathrm{q}sin\phi) \tag{6}$$

$$m\dot{v_x} = F_t(cos\phi cos\ \ \varphi sin\theta+sin\phi sin\varphi \tag{7}$$

$$m\dot{v_y} = F_t(cos\phi sin\ \ \varphi sin\theta+cos\phi sin\varphi \tag{8}$$

$$m\dot{v_z} = -mg + F_t cos\phi cos\theta \tag{9}$$

From the equation, it can be seen that the rate, angle, and speed changes of the UAV are interlocked, which plays a critical role in the subsequent design of its controller.

1.2. PID controller

PID controller is widely used in the field of control, with the advantages of simple realization, adaptability and robustness [2, 4, 5]. It is mainly a linear combination of proportional adjustment of error, integral accumulation, differential prediction of the three parts to realize the feedback control of the controlled object [6, 7]. PID block diagram was shown in the Figure 2.

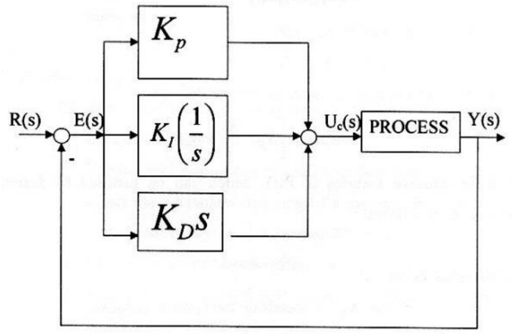

Figure 2. PID block diagram(photo credited: original)

where Kp, Ki, and Kd are proportional amplification, integral, and differential coefficients, respectively.

1) Scaling factor Kp

Its role is to amplify the deviation e(t) between the given value and the measured value proportionally in the control process of the system, so as to improve the response speed of the system and make the system deviation change in the direction of the minimum. However, if the value of Kp is too large, it will make the system oscillate and become unstable, and at the same time, the system's overshooting increases and the dynamic performance deteriorates; if the value of Kp is too small, it reduces the system's regulation accuracy, and at the same time, the system's response speed becomes slower.

2) Integral coefficient Ki

Its role is mainly to minimize the static error of the control system, but it increases the instability of the system. If Ki is high, the system will go into the integral saturation state at the start of the system response, which will bring on the system to produce a large overshoot; if Ki is small, it is difficult to lessen or remove the static error of the system, which will reduce the control system regulation accuracy.

3) The differential coefficient Kd

Its role is to improve the stability of the system and the dynamic response speed, predictive, can reflect the trend of the deviation signal, that is, in the system does not produce deviation before, has been pulled back to the normal state by the differential adjustment effect, thus greatly improving the dynamic performance of the system. However, if the value of Kd is too large, the degree of braking in the response process will be increased in advance, leading to the extension of the adjustment time and adversely affecting the system's anti-jamming performance; if the value of Kd is too small, it is too weak for the differential regulation of the system and cannot inhibit the system's deviation well. Schematic diagram of UAV cascade PID was shown in the Figure 3.

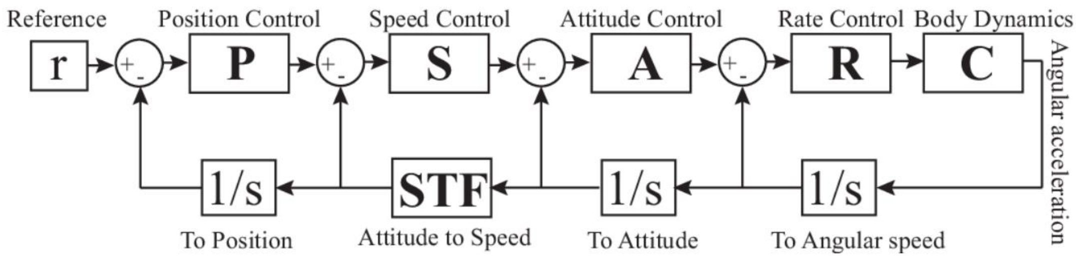

Figure 3. Schematic diagram of UAV cascade PID (photo credited: original)

UAV PID control is mainly divided into the following rings, position ring, velocity ring, acceleration ring, current ring. For the UAV, the serial PID method is adopted, and the output of the outer ring is equal to the input of the inner ring for step-by-step adjustment.

The main formula is:

$$u(t) = K_p(e(t) + \frac{1}{T_t}\int_0^t e(t)dt + T_D\frac{de(t)}{dt} \tag{10}$$

2. SIMULINK Simulation

Simulink, developed by Mathworks, U.S.A., is a visual simulation tool within MATLAB. It provides a modular graph environment for conducting multi-domain simulations and facilitating model-based design. It facilitates embedded system design, simulation, automatic code creation, and ongoing testing and embedded system verification. It facilitates dynamic system modeling and simulation with its graphical editors, modifiable module libraries, and solvers.

Simulink is a software tool that is integrated with MATLAB, allowing for the incorporation of MATLAB algorithms into models and the exportation of simulation results to MATLAB for further analysis. Simulink finds applications in various domains such as automotive, aircraft, industrial automation, large-scale modeling, complicated logic, physical logic, and signal processing. Simulation of a UAV kinematic system was shown in the Figure 4.

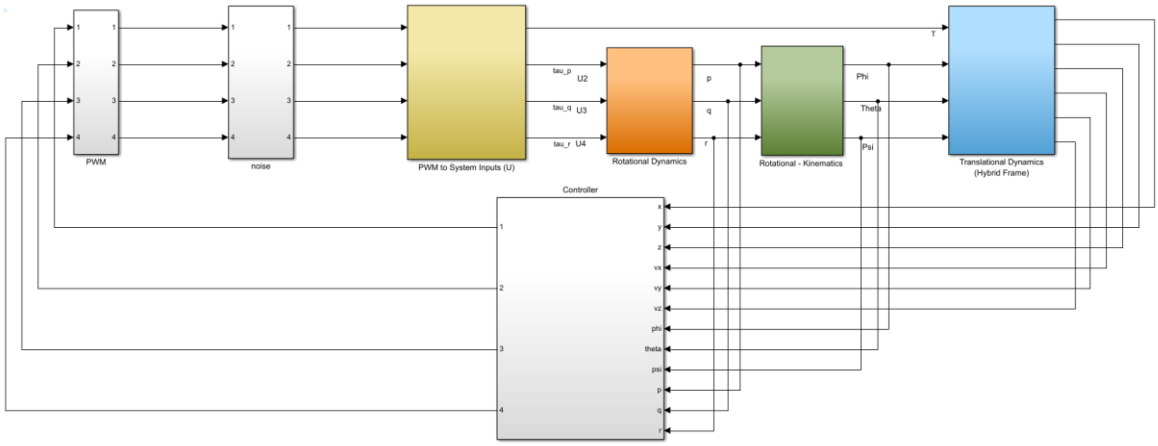

Figure 4. Simulation of a UAV kinematic system (photo credited: original)

Based on the previous analysis of the physical layer, the UAV controller is built and the output waveforms can be viewed by the oscilloscope function.

3. Genetic algorithms

The Genetic Algorithm (GA) is an optimization technique for stochastic global search. Initially created for simulating biological systems on computers, it employs a randomized approach to efficiently explore and find optimal solutions, which simulates the natural selection and inheritance of replication, crossover (crossover) and mutation (mutation) and other phenomena that occur from any initial population (Population), The population advances to a better and better location in the search space by random selection, crossover, and mutation processes, producing a group of individuals more suited to the environment, allowing for generation after generation of continuous reproduction and evolution, and finally converge to a group of the most adapted to the environment. The process involves random selection, crossover, and mutation to create a cluster of individuals that are better adapted to the environment. As a result, the group develops to an ever-better region in the search space, continuing to reproduce and evolve generation after generation, and eventually converge to a flock of the most adapted to the situation of the individual (Individual), so as to seek a high-quality solution to the problem [8-10].

Currently, numerous optimization methods exist for determining PID parameters, including indirect optimization, gradient, and hill-climbing methods. However, in the thermal system, the haploid and expert rectification methods are more commonly employed. Despite their advantageous optimization characteristics, these approaches do have certain limitations. For instance, the haploid method is sensitive to initial values and can easily become trapped in local optimization solutions, leading to suboptimal outcomes. On the other hand, the expert rectification approach heavily relies on prior experience and requires significant effort to organize relevant knowledge bases, as different objective functions correspond to different experiences. Thus, for parameter optimization, the genetic algorithm represents an effective combination technique that can identify the global optimal solution without any need for prior knowledge.In this project, genetic algorithm is used to auto-tune the PID parameters, trying to get more stable PID parameters by this mechanical learning algorithm.

The main tasks are: 1) Determine the number of variables, which is optimized for PID control, and the number of all variables is 3; 2) Determine the upper population limit, number of iterations, crossover, mutation, and self-replication probabilities, initialize, and calculate the final Kp, Ki, Kd parameters.

The realization flowchart is as follows:

Genetic algorithm parameter tuning flowchart was shown in the Figure 5.

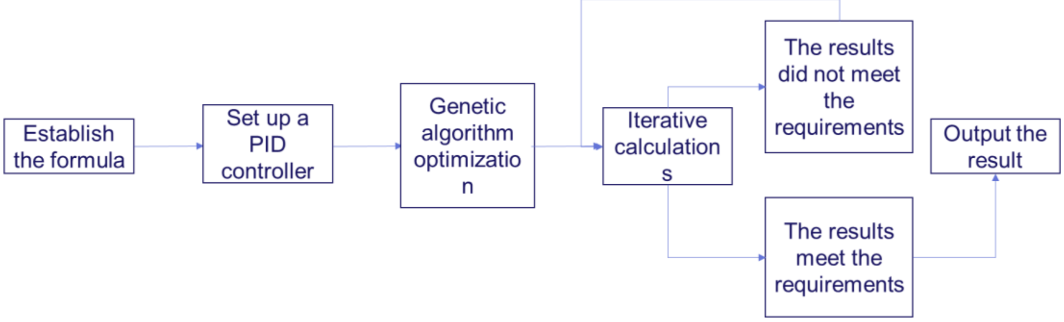

Figure 5. Genetic algorithm parameter tuning flowchart (photo credited: original)

4. Comparison of algorithms

The Ziegler-Nichols method, named after two engineers from Taylor Instruments who proposed it in the early 1940s, is a technique used for tuning a PID controller and exploring its control parameters. It is a conventional approach to PID tuning that heavily relies on past engineering experience to optimize the system's performance. Ziegler-Nichols data sheet was shown in the Table 3.

Table 3. Ziegler-Nichols data sheet

Type of controller	K_p	T_i	T_d
P	$0.5K_{cr}$	∞	0
PI	$0.45K_{cr}$	$0.83P_{cr}$	0
PID	$0.6K_{cr}$	$0.5P_{cr}$	$0.125P_{cr}$

Adjust Kcr according to the output waveform and manually make parameter adjustments according to the table.

The realization process is as follows

Ziegler-Nichols assistant process was shown in the Figure 6.

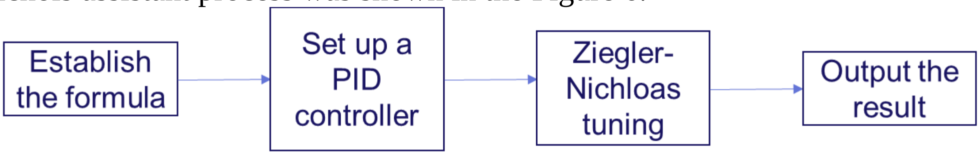

Figure 6. Ziegler-Nichols assistant process (photo credited: original)

5. Results

5.1. Comparison results

Comparative analysis of output results was shown in the Figure 7:

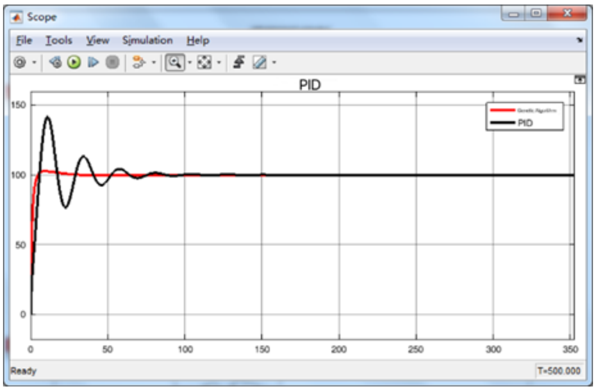

Figure 7. Comparison of results(photo credited: original)

As shown in the figure, the red line is the effect of genetic algorithm parameterization, and the black line is the effect of Ziegler-Nichols parameterization, the traditional parameterization: maximum overshooting amount Mp=41%, and the regulation time ts=78.3ms, the genetic algorithm parameterization: maximum overshooting amount Mp= 2%, and the regulation time ts=21.6ms, which shows that the effect of the genetic algorithm in adjusting the PID is better than that of the traditional method. The system stability obtained by the genetic algorithm is better and the response time is faster.

5.2. Summary of results

The genetic algorithm is utilized to improve the PID control algorithm for the flight attitude control problem of UAVs. Simulation experiments are carried out in Simulink to verify that compared with the traditional PID controller, the fuzzy PID controller improved based on genetic algorithm proposed in this paper has more accurate control effect and can provide reference for improving the flight stability of UAV.

5.3. Shortcomings and enhancements

The results of this simulation are compared and analyzed only for unit step signals, whereas the control signals of UAVs in real life are complex and this simulation is based on an ideal state simulation without taking into account the perturbation variables in reality. More optimization and debugging is still needed to apply this controller in reality.

6. Conclusion

In this paper, the parameters of the UAV motion system are determined by genetic algorithm, and the UAV motion control system is simulated through Simulink in Matlab. The simulation and comparison experiments were carried out by the genetic algorithm to determine the PID and the traditional Ziegler-Nichols method of adjusting the PID parameters, and the parameters of the genetic algorithm were determined by the algorithm in the debugging process, and the time was very short. The experimental results show that the PID control system tuned by genetic algorithm is much better than the traditional parameter tuning method in terms of overshoot and adjustment time. Compared with the traditional parameter tuning method, the overshoot amount is reduced by 39% and the adjustment is reduced by 56.7ms. It can be determined that in the UAV motion system, compared with the traditional way of parameter tuning, the PID parameters are tuned by genetic algorithm to determine the system parameters more quickly, and the overshoot and adjustment time of the UAV kinematics system can be controlled smaller and faster, so that the system adjustment is more stable. Therefore, the genetic algorithm can be used as an effective method to tune the parameters of the UAV system. It will help to establish a UAV control system in the future.

Authors Contribution

All the authors contributed equally and their names were listed in alphabetical order.

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