PID parameters tuning of UAV flight control system based on artificial bee colony algorithm

Feng LIN[1, a], Xiaotong Wang[2, b], Xiaoguang Qu[3, c]

[1]School of Automation, Shenyang Aerospace University, Shenyang, 110136, China

[2]School of Automation, Shenyang Aerospace University, Shenyang, 110136, China

[3]School of Automation, Shenyang Aerospace University, Shenyang, 110136, China

[a]email: lfshenyang163@163.com, [b]email:zmxtbf@163.com, [c]email:qxgshenyang163@163.com

Keywords: Artificial Bee Colony Algorithm; UAV Flight Control System; PID Parameters Tuning

Abstract. In this paper, the PID parameters of flight controller are tuning by artificial bee colony algorithm. Respectively, PID control and simulate the laws of pitching-pose-holding-mode and rolling-pose-holding-mode, which compared with the conventional PID control. The results show that the artificial bee colony algorithm tuning PID parameters (hereinafter referred to as ABC PID) has small overshoot, fast response and less oscillation, which can improve the control performance of the flight control system effectively.

Introduction

UAV [1] has the advantages of small volume, convenient use, low cost, low requirements on the combat environment etc., which has been widely used in various fields. The UAV's action must rely UAV autopilot to complete, so the design of UAV autopilot control law [2][3] is crucial.

At present, most UAV uses the classical PID controller [4], but repeated tests are needed to determine the gain, and cannot guarantee optimal performance and robustness of the control system. Hence, the parameters of the controller must tuning parameters [5]. Artificial bee colony algorithm [6] is an optimization method proposed by imitating the behavior of bees; that is a specific application of swarm intelligent thought [7]. The algorithm has fast convergence speed [8], which commonly used in solving multivariable function optimization.

Aiming at the needs of small fixed-wing UAV flight control system [9], which researching artificial bee colony algorithm and the application of traditional PID control law on the UAV flight control system. The parameters of the PID controller are optimized by artificial bee colony algorithm, and are simulated through matlab [10]. The results of simulation experiments show that the method has better stability and robustness.

The basic principle of the PID controller

In the control system, the most commonly used control of the controller is PID control law [11]. PID control is a linear control method which according to the given value r(t) and the actual output value y(t) constituting the control deviation e(t), i.e., e(t)=r(t)-y(t). Then e(t) do the three operations of proportion, integration and differential, which adding the result so that obtain control output u(t). In the continuous-time domain, the algorithm expression of PID controller is as follows:

$$u(t) = k_p[e(t) + \frac{1}{T_i}\int_0^t e(t)dt + T_d \frac{de(t)}{dt}] \qquad (1)$$

In the type (1): k_p is proportional coefficient; k_i is integral coefficient; k_d is differential coefficient.

The correct role of PID controller various aspects are as follows:

Proportional element: Deviation signal e(t) is proportional to the reaction of control system. While the deviation once produced, controller generates control action immediately in order to reduce the deviation.

Integral element: Mainly used to eliminate the steady-state error and improve the indiscrimination degree of system. Integral action depends on the strength of the integration time constant. The larger integration time constant is, the weaker integral action will be, conversely stronger.

Differential element: Reflecting the trend of deviation signal change, and adjusting the differential output of error. System will be controlled in time when the error mutations, and engender an early effective correction signal in order to speed up the movement speed of the system and reduce the adjustment time.

Combining by the advantages of the three, the system will obtain the control performance which optimized.

Artificial bee colony algorithm tuning PID parameters

In the problem of ABC PID, three parameters of PID can be combined together as all possible solutions to represent each of the nectar source, through the deviation e(t) as a fitness function, then simulate the process of honey bees and calculate fitness value in real time in order to achieve the dynamical adjust of k_p, k_i and k_d, and ultimately find a best value of the three parameters. The block diagram of ABC PID is shown in Figure 1.

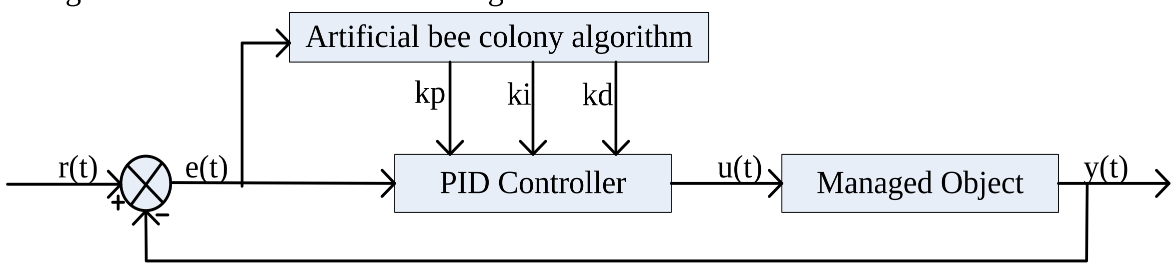

Fig.1. The block diagram of ABC PID

Specific steps:

Step1: Initialization. Set the number of iterations, the colony size, sampling time, the percentage of scouting bees, the upper and lower limits of k_p, k_i and k_d, and generate an initial population of N -containing solution randomly according to the formula (2).

$$x_i = LB + rand(0,1) * (UB - LB) \quad (2)$$

In the formula: LB is the lower limit of the range of x, UB is the upper limit of the range of x.

Step2: Leading bees search around the neighborhood according to the formula (3), and calculate the fitness value, choose a better nectar source by greedy method.

$$x'_{ij} = x_{ij} + r_{ij}(x_{ij} - x_{kj}) \quad (3)$$

In the formula: $j = 1,2,3$, $k = 1,2,\cdots,\mathrm{N}$, besides $j \neq k$, r_{ij} is a random number in [-1,1].

Step3: The following bees according to the formula (4) to calculate the probability and choose nectar source where gather honey.

$$P_i = \frac{fit(i)}{\sum_{i=1}^{N} fit(i)} \quad (4)$$

In the formula: P_i is the probability that the i-th nectar source is selected. fit(i) is the fitness of the i-th solution.

Fitness value is calculated as follows:

$$fit(i) = \begin{cases} \dfrac{1}{1+f_i} & f_i > 0 \\ 1 + abs(f_i) & f_i < 0 \end{cases} \quad (5)$$

In the formula: f_i is the objective function value.

Step4: The following bees search around the neighborhood according to the formula (3), and calculate the fitness value, choose a better nectar source.

Step5: Determine a leading bee whether become a scouting bee or not. The quality of a solution has not improved if the search time of the solution greater than limit, the solution will be abandoned. The leading bee becomes scouting bee and in accordance with the formula (6) to produce a new solution instead.

$$x_{ij} = x_{\min,j} + rand(0,1) * (x_{\max,j} - x_{\min,j}) \quad (6)$$

In the formula: $x_{\min,j}$ is the minimum of j-th dimension currently, $x_{\max,j}$ is the maximum of j-th dimension currently.

Step6: Record the best solution at this time.

Step7: Determine whether satisfy the termination condition or not. If it is, then output the optimal solution, otherwise add one to the number of iterations and jump back to step2.

Mathematical model of UAV

Mathematical model of UAV is by the combination of force equations, moment equations, motion equations and navigation equations to determine the relationship between state vector $X^T = [u \quad v \quad w \quad \phi \quad \theta \quad \psi \quad p \quad q \quad r \quad x_g \quad y_g \quad h]$ and input control $U^T = [\delta_T \quad \delta_e \quad \delta_a \quad \delta_r]$, and establish a nonlinear model. Then choose a flight movement with constant in straight line, symmetric steady and no sideslip, which as a reference movement of UAV. According to Small-perturbation Theory, the nonlinear model is linearized. After decoupling we can obtain the linear model of longitudinal and lateral movement.

Take pitching-pose-holding-mode and rolling-pose-holding-mode for instance, performing PID parameters tuning and simulating the control loop.

Assuming UAV fly at the height of 500m with 20m/s speed in the air, the angle of attack is 2°, glide angle is -2°, and combine with aerodynamic derivative formula to obtain the longitudinal state matrix.

$$A = \begin{bmatrix} -0.03667 & 7.405 & 0 & -9.8000 \\ -0.00915 & -2.611 & 1 & 0 \\ 0.00323 & -16.14 & -1.364 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix}, B = \begin{bmatrix} -0.2357 \\ -0.09795 \\ -13.04 \\ 0 \end{bmatrix}$$

$$C = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}, D = \begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \end{bmatrix}$$

We can get the transfer function through Laplace transform. Thus the control loop of pitching-pose-holding-mode is shown in Figure 2.

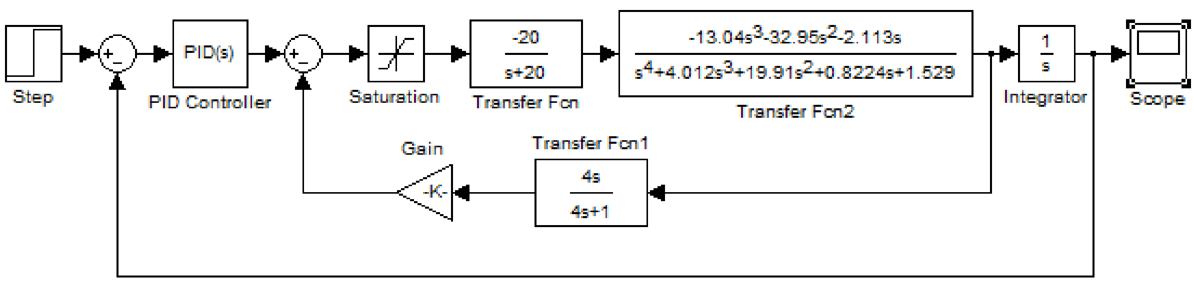

Fig.2. The control loop of pitching-pose-holding-mode

Similarly, the lateral state matrix is:

$$A=\begin{bmatrix}-0.2277 & 0 & -1.0000 & 0.2159\\ -13.75 & -11.81 & 3.324 & 0\\ 10.61 & -0.3601 & -0.3661 & 0\\ 0 & 1 & 0 & 0\end{bmatrix}, B=\begin{bmatrix}0 & 0.1001\\ -117.9 & 8.936\\ -0.304 & -6.671\\ 0 & 0\end{bmatrix}$$

$$C=\begin{bmatrix}1 & 0 & 0 & 0\\ 0 & 1 & 0 & 0\\ 0 & 0 & 1 & 0\\ 0 & 0 & 0 & 1\end{bmatrix}, D=\begin{bmatrix}0 & 0\\ 0 & 0\\ 0 & 0\\ 0 & 0\end{bmatrix}$$

And the control loop of rolling-pose-holding-mode is shown in Figure 3.

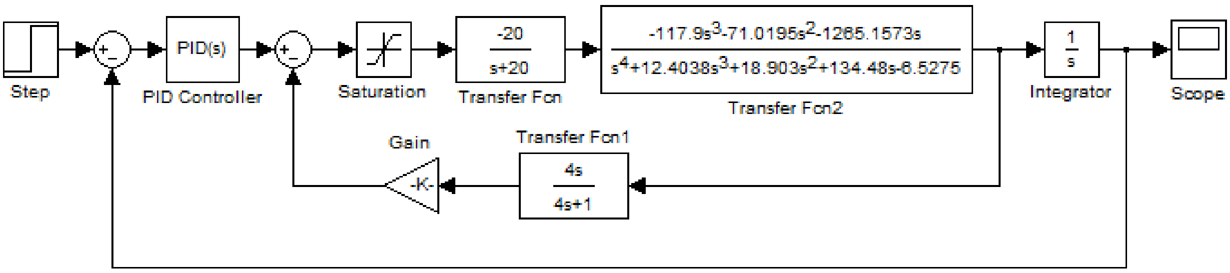

Fig.3. The control loop of rolling-pose-holding-mode

PID parameters tuning and simulation

In the control loop of pitching-pose-holding-mode, we can obtain the conventional PID parameters through regulation: $k_p = 3.1995, k_i = 0.4859, k_d = 1.0135$. The process of ABC PID is shown in Figure 4. The ABC PID is: $k_p = 5.3460, k_i = 0.8225, k_d = 0.3185$. And simulate the two sets of PID parameters, the results is shown in Figure5. In Figure5, the dotted line is the step response of conventional PID; the solid line is the step response of ABC PID.

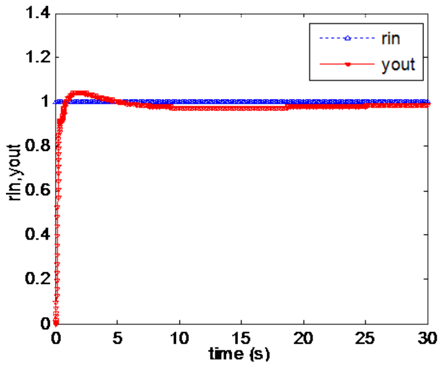

Fig.4. The process of ABC PID

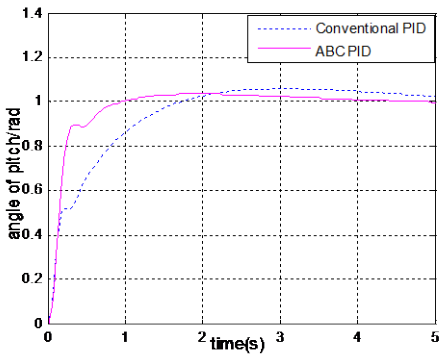

Fig.5. The Simulation results

Similarly, in the control loop of rolling-pose-holding-mode, the conventional PID is: $k_p = 0.8546, k_i = 0.4769, k_d = 0.1256$, ABC PID is: $k_p = 1.4235, k_i = 0.2416, k_d = 0.0894$. The process of ABC PID is shown in Figure 6. And simulate the two sets of PID parameters, the results is shown in Figure7. In Figure7, the dotted line is the step response of conventional PID; the solid line is the step response of ABC PID.

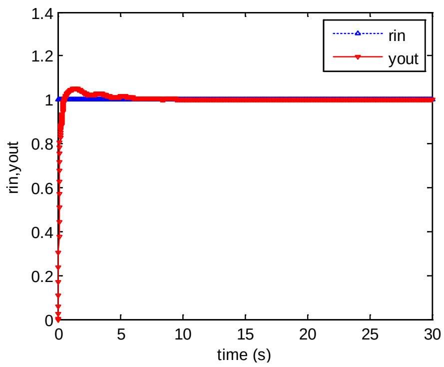

Fig.6. The process of ABC PID

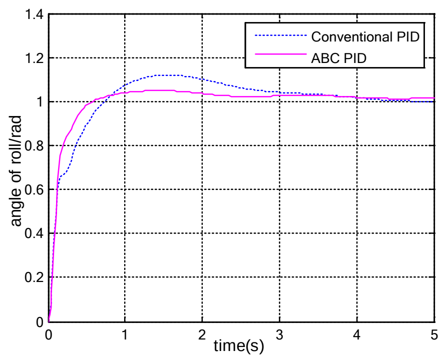

Fig.7. The Simulation results

According to Figure6 and Figure8, ABC PID has a more significant improvement than conventional PID in rise time, settling time, overshoots and other indicators.

Summary

The PID parameters of pitching-pose-holding-mode and rolling-pose-holding-mode are tuning by artificial bee colony algorithm, and contrast with conventional PID parameters in the simulation. The simulation results show that the ABC PID has the advantages of small overshoot, fast response and less oscillation, which can improve the control performance of the flight control system effectively. The flight control system will be stable, rapid and robust.

References

[1] Fen Dang, Minfang Wang, Yinhui Wang. UAV Development Status and Trends [J]. Ground Air Defense Weapons. 2005(3):49-54.

[2] Eric N.Johnson, Sebastien G.Fontaine, Aaron D.Kahn. Minimun Complexity Uninhabited Air Vehicle Guidance and Flight Control System. IEEE. 2001,

[3] Gao J, Chen Z. Study on Gain-scheduling Problem in Flight Control [J]. Chinese Journal of Aeronautics. 1999:12(4)

[4] Huayi Wang, Xixia Yang. Automatic Control Theory [M]. Beijing: Publishing House of National Defense Industry. 2009.

[5] Ruiyou Huang, Liguo Qu. PID Controller Parameter Tuning and Implementation [M]. Beijing: Publishing House of Science. 2010.

[6] Karaboga D. An Idea Based on Honey Swarm for Numerical Optimization, TR06 [R]. Kayseri: Erciyes University. 2005.

[7] Xiujuan Lei. Swarm Intelligent Optimization Algorithms and Their Application [M].Beijing: Publishing House of Science. 2012.

[8] Magdalene M, Yannis M, Constantin Z. Honey bees mating optimization algorithm for financial classification problems [J]. Applied Soft Computing. 2010 10(3):806-812.

[9] Sentang Wu, Yuhua Fei. Flight Control System [M]. Beijing: Publishing House of Beihang University. 2005.

[10] Shuying Yang, Hua Zhang. Swarm Intelligence and Bionic Computing [M]. Beijing: Publishing House of Electronics Industry. 2012.

[11] Jinkun Liu. Advanced PID Control MATLAB Simulation [M]. Beijing: Publishing House of Electronics Industry. 2011.