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# *Path Tracking Control of Patrol Unmanned Vehicle Based on GWO-PID*

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***Keywords:*** Gray Wolf Optimization Algorithm, Path Tracking, Patrol Unmanned Vehicle

***Abstract:*** Aiming at the problems that the traditional PID control parameters are complex to set and it is difficult to find the optimal parameters, which affects the accuracy and stability of the path tracking control of patrol unmanned vehicles, a GWO-PID path tracking control system is designed by combining gray wolf optimization algorithm with PID control algorithm. In this paper, the kinematic model of patrol unmanned vehicle is established at first, and the corresponding simulation model is designed in MATLAB. The front wheel angle is controlled by PID controller to realize the path tracking of the unmanned vehicle; Then gray wolf optimization algorithm is used to optimize the parameters of PID control, and the optimized parameters are simulated. The results show that the optimized PID controller has better control effect; Finally, the actual path tracking test is carried out with reference to the optimized parameters, and the test effect is good.

## 1. Introduction

Patrol unmanned vehicle is a typical mobile robot, which can perform patrol tasks on all kinds of paved roads or field environments. It plays an increasingly important role in industry, agriculture and service industry. Since the working environment of patrol unmanned vehicles is mostly dangerous or remote, it is of great significance to improve the autonomy of unmanned vehicles and enable them to perform patrol tasks independently [1].

In order to enable the unmanned vehicle to successfully perform the patrol task, it is necessary to control the unmanned vehicle to track the pre-set inspection path smoothly, accurately and quickly. At present, a variety of path tracking algorithms for unmanned vehicles have been proposed, such as PID control, preview tracking optimal control, model predictive control and so on[2]. PID control principle is simple, robust and practical, which is widely used in all kinds of control systems [3]. However, it is often difficult to adjust parameters and poor dynamic effect for complex control systems.

Gray wolf optimization algorithm is a new meta heuristic algorithm inspired by gray wolf group behavior. It is widely used in engineering theory and practice because of its fast convergence speed and few parameters in solving some optimization problems [4]. It has been proved that in function optimization, the solution accuracy and convergence are significantly better than those of particle swarm optimization, differential evolution algorithm and genetic algorithm [5].

Aiming at the problems of complex parameter setting and poor dynamic effect of PID control algorithm, this paper designs a GWO-PID path tracking control system. The gray wolf optimization algorithm is used to optimize the parameters of the PID controller to improve the path tracking control accuracy and stability of the PID controller. Finally, the performance of the algorithm is verified by simulation experiments and actual tests.

## 2. Kinematic Model

This paper takes the four-wheel inspection unmanned vehicle as the controlled object, and selects the unmanned vehicle based on ackerman steering structure, in which the front wheel of the vehicle controls the direction of motion, and the rear wheel acts as the driving wheel to provide power. The kinematic model of the unmanned vehicle is shown in Figure 1, where $XOY$ is the inertial coordinate system and $xoy$ is the vehicle body coordinate system. $\Phi$ is the yaw angle of the vehicle, and counterclockwise is positive. Assuming that the vehicle moves linearly or circularly around a point at any time and ignores the effect of suspension, the steering motion model of the vehicle can be obtained [6].

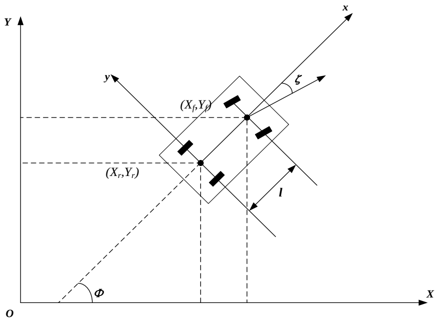



Figure 1: Kinematic model of unmanned vehicle.

Where, $(X_r, Y_r)$ and $(X_f, Y_f)$ are the coordinates of the center of the rear axle and the center of the front axle of the vehicle in the inertial coordinate system, $v_r$ is the speed of the vehicle at the center of the rear axle, $l$ is the wheelbase, and $R$ is the instantaneous steering radius at the center of the rear axle, $\zeta$ is the front wheel deflection angle.

At the driving center $(X_r, Y_r)$ of the rear axle, the speed is:

$$v_r = \dot{X}_r \cos \Phi + \dot{Y}_r \sin \Phi \tag{1}$$

The kinematic constraints of the front and rear axles are:

$$\dot{X}_f \sin(\Phi + \zeta) - \dot{Y}_f \cos(\Phi + \zeta) = 0 \tag{2}$$

$$\dot{X}_r \sin \Phi - \dot{Y}_r \cos \Phi = 0 \tag{3}$$

From the above three formulas:

$$\dot{X}_r = v_r \cos \Phi \tag{4}$$

$$\dot{Y}_r = v_r \sin \Phi \tag{5}$$

According to the geometric relationship of the front and rear wheels:

$$X_f = X_r + l \cos \Phi \tag{6}$$

$$Y_f = Y_r + l \sin \Phi \tag{7}$$

Vehicle yaw rate:

$$\omega = \frac{v_r}{l} \tan \zeta \tag{8}$$

Among them, $\omega$ is the vehicle yaw rate; At the same time, by $\omega$ and vehicle speed $v$ to obtain steering radius $R$ and front wheel deflection angle $\zeta$:

$$R = \frac{v_r}{\omega} \tag{9}$$

$$\zeta = arctan \frac{l}{R} \tag{10}$$

From the above formula, the vehicle kinematics model is:

$$\begin{bmatrix} \dot{X}_r \\ \dot{Y}_r \\ \dot{\Phi} \end{bmatrix} = \begin{bmatrix} cos\,\Phi \\ sin\,\Phi \\ 0 \end{bmatrix} v_r + \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix} \omega \tag{11}$$

## 3. Design of Path Tracking Controller

The schematic diagram of patrol unmanned vehicle path tracking control is shown in Figure 2. When the unmanned vehicle tracks the path, it first needs to select the path point closest to the vehicle as the target point, and then calculate the horizontal distance between the vehicle and the target point as the horizontal tracking error, and design the corresponding path tracking controller to track the path.

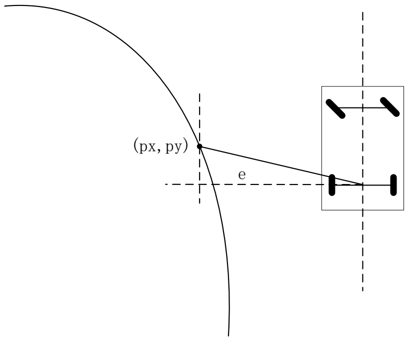



Figure 2: Schematic diagram of unmanned vehicle path tracking.

PID control method has the advantages of convenient use and simple algorithm. It is widely used in industrial control, automatic driving and other fields. The structural block diagram of the PID path tracking controller is shown in Figure 3. The lateral deviation between the vehicle and the desired path is used as the input of the PID controller, the target heading angle of the vehicle is calculated and output by the PID controller, and the adjustment of the front wheel angle is controlled by the steering actuator to realize the path tracking control.

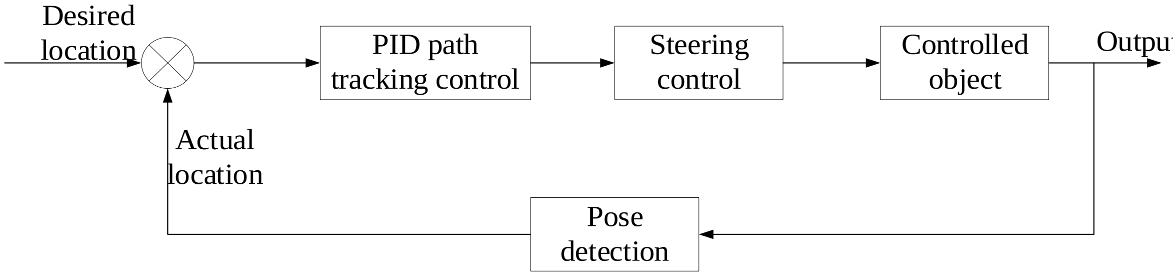



Figure 3: PID path tracking control structure block diagram.

The expression of PID controller is as follows:

$$u(t) = K_p e(t) + K_i \int e(t)\, dt + K_d \frac{de(t)}{dt} \tag{12}$$

Where, $u(t)$ is the output of PID controller, $e(t)$ is the input of PID controller, $K_p$ is the proportional coefficient, $K_i$ is the integral coefficient, $K_d$ is the differential coefficient.

## 4. PID Control Parameter Optimization

### 4.1 Gray Wolf Optimization Algorithm

The grey wolf optimization algorithm is an optimization search method inspired by the grey wolf's predatory activities. It has the characteristics of simple structure, few parameters, easy implementation and so on [7]. In recent years, it has been widely used in parameter optimization, workshop scheduling, image classification and other fields.

The gray wolf group has a strict social hierarchy. $\alpha$ represents the gray wolf at the first level, gray wolves in the second level are represented by $\beta$, $\delta$ represents the gray wolf at the third level, and $\omega$ represents the gray wolf at the fourth level. Among them, the gray wolf at the upper level has absolute control over the gray wolf at the next level. In the gray wolf optimization algorithm, in order to simulate the hierarchy of the gray wolf group and simplify the algorithm, assume that there is a gray wolf $\alpha$, $\beta$ and $\delta$ respectively. Among them, the positions of $\alpha$, $\beta$ and $\delta$ represent the best solution, optimal solution and suboptimal solution respectively, and the position of $\omega$ is other candidate solution.

Gray wolf optimization algorithm randomly initializes the gray wolf group, and determines the optimal solution, optimal solution and suboptimal solution by calculating the individual fitness value in the iterative process, that is, the positions of $\alpha$, $\beta$ and $\delta$ are obtained [8].

Gray wolf optimization algorithm mainly includes three parts in the optimization process: tracking and chasing, chasing and surrounding, and attacking prey.

(1)Surround prey

The behavior of gray wolves in hunting prey is defined as follows:

$$D = |CX_p(t) - X(t)| \tag{13}$$

$$X(t+1) = X_p(t) - AD \tag{14}$$

$$A = 2ar_1 - a \tag{15}$$

$$C = 2r_2 \tag{16}$$

Formula (13) is used to calculate the distance between individuals and prey, and formula (14) is used to update the position of gray wolf individuals. $X_p(t)$ is the position vector of prey in the $t$ generation, $X(t)$ is the position vector of gray wolf individuals in the $t$ generation, A and C are coefficients, $a$ is the convergence factor that decreases with the number of iterations, $r_1$ and $r_2$ are random numbers between [0,1].

(2)Hunting

Gray wolves $\alpha$, $\beta$ and $\delta$ know more about the potential location of prey. These three gray wolves lead other gray wolves to update the location and gradually approach the prey. The definition of individual tracking prey in wolves is as follows:

$$\begin{cases} D_\alpha = |C_1 X_\alpha - X| \\ D_\beta = |C_2 X_\beta - X| \\ D_\delta = |C_3 X_\delta - X| \end{cases} \tag{17}$$

$D_\alpha$, $D_\beta$ and $D_\delta$ represent the distance between $\alpha$, $\beta$ , $\delta$ and other individuals respectively; $X_\alpha$, $X_\beta$ , $X_\delta$ represent the current positions of $\alpha$, $\beta$ and $\delta$ respectively; $C_1$, $C_2$ and $C_3$ are random vectors, and $X$ is the current position of the gray wolf.

$$\begin{cases} X_1 = X_\alpha - A_1 D_\alpha \\ X_2 = X_\beta - A_2 D_\beta \\ X_3 = X_\delta - A_3 D_\delta \end{cases} \tag{18}$$

$$X(t+1) = (X_1 + X_2 + X_3)/3 \tag{19}$$

Equation (18) defines the step length and direction of individual $\omega$ in the wolf pack towards $\alpha$, $\beta$ and $\delta$, and equation (19) defines the final position of $\omega$.

(3)Attack prey

During the hunting process of gray wolves, the value of a is gradually reduced, so the fluctuation range of a is also reduced, so the fluctuation range of A is also reduced. When $|A| > 1$, the gray wolf is forced to separate from its prey (local optimal), hoping to find a more suitable prey (global optimal); At time $|A| < 1$, wolves attacked their prey.

### 4.2 GWO Algorithm Optimizes PID Parameters

PID controller has the advantages of convenient use, but its parameter tuning is complex, and it is difficult to achieve the optimal control effect by simply relying on empirical method. Therefore, this paper uses gray wolf optimization algorithm to optimize PID parameters to ensure the accuracy and stability of unmanned vehicle path tracking, and achieve satisfactory control effect. The flow chart of grey wolf optimization algorithm optimizing PID control parameters is shown in Figure 4.

The fitness function can determine the advantages and disadvantages of gray wolf optimization algorithm. In the process of path tracking, the function of the fitness function is to ensure that the vehicle can track the desired path quickly and smoothly. Therefore, this paper constructs the fitness function according to the deviation of path tracking and the input of control quantity.

$$J = \sum_{i=1}^{n} (|e_i| + |\Delta u_i|) \tag{20}$$

Where $e_i$ is the deviation between the actual position and the desired path at time $i$, and $\Delta u_i$ is the input of the unmanned vehicle control quantity at time $i$. The first item reflects the tracking ability of the unmanned vehicle to the desired trajectory, and the second item reflects the stability of the vehicle during driving.

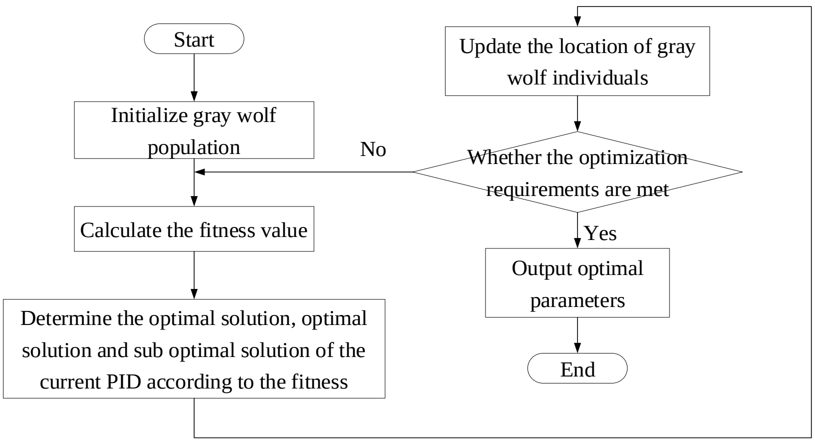



Figure 4: GWO Algorithm Optimization PID parameter flow chart.

## 5. Simulation and Test

This paper takes the four-wheel patrol unmanned vehicle with ackerman steering structure as the controlled object for simulation and test. The physical diagram of the unmanned vehicle is shown in Figure 5. The vehicle wheelbase is 1m, the maximum deflection angle of the front wheel is 45 °, and the maximum driving speed is 1.5m/s.

Figure 5: Physical drawing of unmanned vehicle for test.

### 5.1 Simulation and Result Analysis

In order to verify the effect of GWO-PID control algorithm on path tracking, a path tracking simulation model is built in matlab. Equation (20) is used as the fitness function, and the traditional PID control algorithm and GWO-PID algorithm are used for path tracking simulation respectively. Because the expected path of the unmanned vehicle in the actual operation process is a segmented linear path, this paper selects the segmented linear path for simulation, and the expected path is:

$$y=\begin{cases}0.5x, x\leq 10\\ x-5, 10<x\leq 20\\ 2x-25, x>20\end{cases} \tag{21}$$

In GWO-PID algorithm, the number of wolves is 50, the maximum number of iterations is 300, and the value range of $K_p$, $K_i$, $K_d$ is [0,100]. The simulation results are shown in Figure 6.

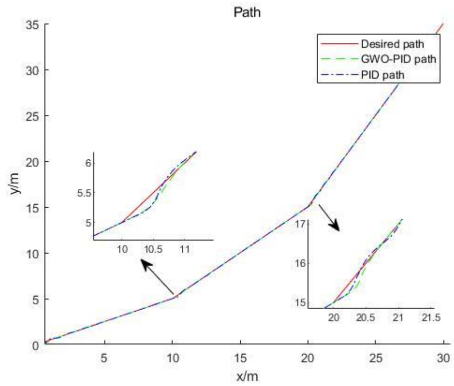



Figure 6: Desired path and actual path.

It can be seen from Figure 6 that the two tracking control methods can track the desired path more accurately. The tracking accuracy, adjustment time and other parameters of the controller optimized by the gray wolf algorithm are better than the traditional PID, and the traditional PID parameter setting process is more complex. The change of unmanned vehicle control quantity is shown in Figure 7.

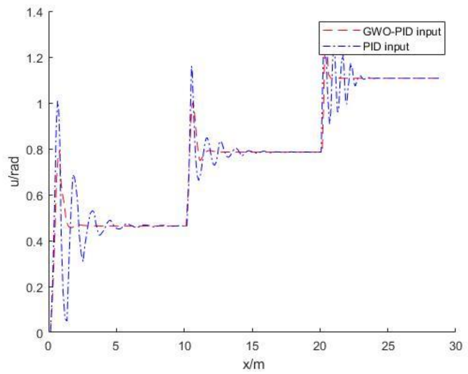



Figure 7: Change of control quantity.

It can be seen from the figure that the adjustment time and stability of the control quantity optimized by the gray wolf optimization algorithm are much better than those of the traditional PID control quantity, and there is basically no mutation, realizing the stable and fast tracking of the desired trajectory. The fitness change of gray wolf optimization algorithm is shown in Figure 8. From the figure, it can be seen that gray wolf optimization algorithm only needs about 35 iterations to achieve good optimization results.

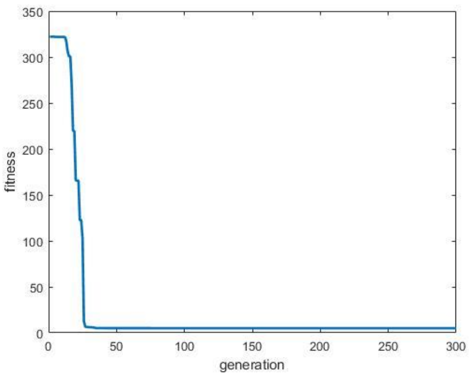
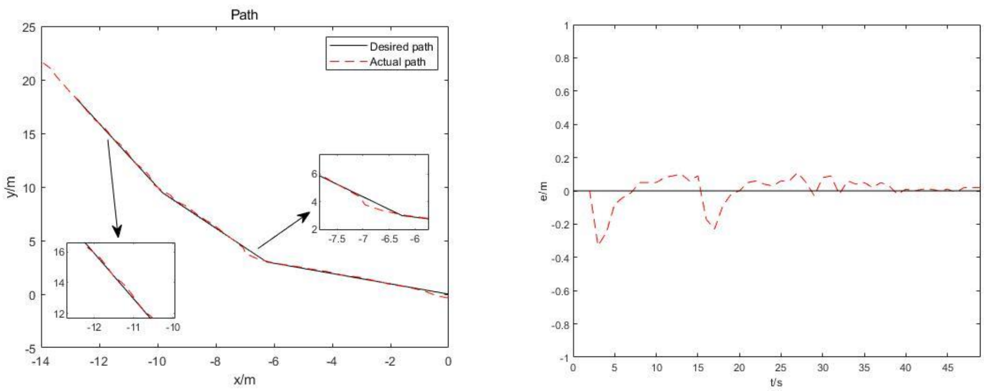



Figure 8: Fitness change.

## 5.2 Actual Test




(a) Desired path and actual path (b) Path tracking deviation

Figure 9: Path tracking results.

In order to verify the actual control effect of GWO-PID algorithm, the actual path tracking test is carried out in the patrol unmanned vehicle with reference to the optimized parameters. The controller of the patrol unmanned vehicle used for the test is STM32 single chip microcomputer. The vehicle uses RTK positioning mode for positioning, and the positioning accuracy can reach centimeter level. The actuator of vehicle steering is high torque steering gear. During the test, the vehicle keeps running at a speed of 0.5m/s, and the test path is an outdoor path about 25m long set in advance. The actual test results are shown in Figure 9.

It can be seen from the figure that there will be a large deviation when the unmanned vehicle starts tracking and reversing. With the passage of time, the deviation gradually decreases and the deviation is basically controlled within 20cm, so the path tracking effect is good.

## 6. Conclusion

Aiming at the problem of path tracking control of patrol unmanned vehicle, this paper designs a path tracking control method based on gray wolf optimization algorithm to optimize the parameters of PID controller. Through gray wolf optimization algorithm, the parameters of PID controller are optimized, and the optimal parameters of PID control are found to improve the stability, accuracy and rapidity of control. Finally, the simulation test shows that the path tracking effect of the optimized algorithm is better than the traditional PID control effect. The actual test shows that the control algorithm can better realize the path tracking of patrol unmanned vehicle.

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