Research on an intelligent path planning algorithm for robot using electrical control technology

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Abstract. In view of the shortcomings of traditional genetic algorithm in path planning, such as infeasible path, falling into local optimization, too many turning times and so on, an improved adaptive genetic algorithm is proposed. A priori knowledge is used to optimize the initial population, and the initial population that does not intersect with obstacles is obtained. The probability formulas of crossover and mutation are designed to avoid falling into local optimization, so as to improve the convergence speed. The smoothness of the path and the shortest path are introduced into the fitness function as the evaluation criteria to make the planned path more efficient. The simulation results show that: compared with the basic algorithm, when the number of obstacles is 20:00, the path of the improved algorithm is reduced by 4.2%; when the number of obstacles is 115, the path is reduced by 25.1%. With the continuous increase of obstacles, the percentage of path reduction shows an upward trend, and the number of iterations of the algorithm and the number of turning points in the path are better than the basic genetic algorithm.

Keywords: omni-directional four-wheel drive; inspection robot; motion control.

1. Introduction
With the rapid development of unattended intelligent substation, the substation patrol robot gradually replaces the traditional manual inspection mode and is widely used in the automatic detection of substation equipment status. Most of the substation inspection robots adopt wheeled structure, and the more common one is the structure of two-wheel differential drive combined with universal wheel follow-up steering. This kind of robot has good flexibility, but poor obstacle surmounting ability.

The omni-directional four-wheel drive mobile robot is driven and controlled by four hub servo motors and four steering servo motors respectively. Through the coordinated control of the rotational speed and centroid deflection of each wheel, the omni-directional four-wheel drive mobile robot can realize a variety of motion modes, such as two-wheel drive, four-wheel drive, oblique, in-situ steering and so on. Its typical representative is the Seekur cleaning robot developed by MobileRobots Company.
In this paper, the author studies the motion control system structure and control strategy of the omni-directional four-wheel drive substation patrol robot, establishes the kinematics model of the robot, and tests the kinematics of the robot to verify the effectiveness of the control strategy.

2. Mechanical structure of mobile platform
The mobile platform of omni-directional four-wheel-drive robot is composed of four sets of driving and steering mechanisms and support plates with the same structure, and the overall size is 550mm × 550mm. The support plate is milled as a whole, with high precision and light weight, and can be used to install industrial computer, battery, head, manipulator and all kinds of detection sensors. Four sets of driving steering mechanisms are symmetrically installed on both sides of the support plate, and each set of mechanisms is composed of driving and steering parts, which are connected by L-shaped brackets. In order to improve the driving ability of the robot, the driving motor adopts a 200W DC brushless disk motor, and is connected with the wheel through a gearbox with a deceleration ratio of 42:1, the maximum running speed of the robot can reach 1.2m / s, and the wheel diameter is 250mm, which can automatically surmount the obstacle within the 100mm.

The steering part is driven by a 120W brushless DC motor, and accurate position feedback is achieved through a digital absolute encoder, thus realizing zero 360 °continuous steering.

3. Motion control system structure
Robot path planning is a non-deterministic complex problem.
Intelligent genetic algorithm is a parallel and global search algorithm by simulating genetic operations in nature.
Because multi-point parallel computing can be carried out at the same time in the parameter space, it is more likely to find the global optimization, and there is no continuous requirement for its search space.
However, intelligent genetic algorithm still has some defects in population generation, fitness function modeling, search efficiency and so on.
Especially in the complex environment, it often takes a lot of time to plan the feasible path.
In order to solve this problem, a robot path planning method based on adaptive genetic algorithm is proposed in this paper.
In this method, the population is initialized according to prior knowledge to shorten the number of iterations, a new adaptive strategy is proposed, and the probability of crossover and mutation is automatically adjusted according to the fitness value to prevent the algorithm from falling into local optimality. Double constraints of shortest path and smoothness are selected to ensure the shortest path and fewer turning times.

4. Research on Control method
The working environment of the mobile robot is represented in the form of a grid map, as shown in figure 1.
In figure 1, the free grid is represented in white, the obstacle grid is represented in black, and the location of the path point can be represented by Cartesian coordinates and grid serial numbers.
Using binary coding, the length and width of the grid are unit length, identifying the grid and coordinates respectively.
The grid sequence number corresponds to its corresponding Cartesian coordinates one by one.

4.1. Representation of robot motion
In the grid map, the robot can move in 8 directions by default when it does not encounter obstacles and does not exceed the boundary of the map.
Although this method can find a feasible path, it increases the variability of the path, leads to excessive turns and path cycles, which affects the convergence speed of the collection method and is not conducive to the operation of the robot. The following improvements are made: the three grids far
away from the target point are discarded in the eight grids around the position of the robot, and the remaining five directions are reserved for initialization, as shown in figure 2.

Figure 1 Robot Model in Global coordinate system

In the figure, $\Sigma G$ is the global reference coordinate system, $\Sigma R$ is the robot body coordinate system, and $\theta$ is the angle difference between the robot body coordinate system and the global coordinate system. $\mathbf{v}_G = [\dot{x}_G, \dot{y}_G, \theta_G]^T$ is used to represent the velocity vector of the robot in the global coordinate system, and $\mathbf{v}_R = [\dot{x}_R, \dot{y}_R, \theta_R]^T$ is used to represent the velocity vector of the robot in the ontology coordinate system, then the motion of the robot in the global coordinate system can be mapped to the robot body coordinate system through equation (1):

$$\mathbf{v}_R = R(\theta)\mathbf{v}_G$$

Where: $R(\theta)$ is an orthogonal rotation matrix:

$$R(\theta) = \begin{bmatrix} \cos \theta & \sin \theta & 0 \\ -\sin \theta & \cos \theta & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

4.2. Robot kinematics model

In genetic algorithm, crossover probability ($P_c$) and mutation probability ($P_m$) play an important role in algorithm convergence and path solving quality, and ($P_c$) and ($P_m$) are fixed in traditional genetic algorithm, which is not conducive to population evolution. $P_c$ selecting too large will destroy the balance of the population, resulting in the destruction of individuals with large fitness values; on the contrary, choosing too small will slow down the speed of population evolution. Similarly, $P_m$ selection is too large and the evolution direction of the population is changeable, which is not conducive to the retention of dominant individuals; too small selection is not conducive to the generation of new individuals, and the algorithm is easy to precociously fall into local optimization.

Therefore, it is difficult to meet the requirements of path planning by using fixed $P_c$ and $P_m$. In order to solve this problem, this paper adaptively adjusts and improves the crossover and mutation, which is adjusted to
Among them, L and W are the length and width of the robot respectively, and the radius of the four wheels is R. Suppose the robot rotates with $O_c(x_c, y_c)$ as the center and the angular velocity of rotation is $\omega_R$, we can know:

$$\begin{align*}
    x_c &= -\frac{y_R}{\omega_R} \\
    y_c &= \frac{x_R}{\omega_R} (\omega_R \neq 0)
\end{align*}$$  \hfill (3)

The deflection angle of each wheel is defined as the angle between the forward direction of the wheel and the X axis of the robot body coordinate system, which is expressed by $\alpha_i (i = 0,1,2,3)$, and the rotational speed of each wheel is $\omega_I$. When the robot is in a rotating state, the axle extension lines of each wheel point to the robot's rotation center $O_c$, and the instantaneous angular velocity of each wheel around the rotation center is the same. The rotation radius of each wheel is represented by $r_i$, and the deflection angle of each wheel can be obtained from figure 2 as follows:

$$\begin{align*}
    \alpha_0 &= \arctan\left(-\frac{2x_c - L}{2y_c + W}\right) \\
    \alpha_1 &= \arctan\left(-\frac{2x_c - L}{2y_c - W}\right) \\
    \alpha_2 &= \arctan\left(-\frac{2x_c + L}{2y_c - W}\right) \\
    \alpha_3 &= \arctan\left(-\frac{2x_c + L}{2y_c + W}\right)
\end{align*}$$  \hfill (4)

5. Experimental results and analysis

The omni-directional four-wheel drive substation inspection robot developed through the above process is shown in figure 3. The motion control process of the robot is realized on the industrial control computer of the robot body. The inspection of substation equipment can be realized by the upper computer planning inspection tasks or hand-held remote control. In order to realize the detection of the higher position of the indoor equipment, the robot head has designed the lifting function, the lifting stroke is 1m, the highest position can be raised to 1.8m, and the maximum lifting speed is 50mm/s.
In order to verify the validity of the robot kinematics model, the kinematics test of the robot is carried out: in the initial state, the global coordinate system coincides with the robot body coordinate system, the motion velocity $v_G$, of the robot body in the global coordinate system is given, and the expected trajectory of the robot at a given speed is calculated. Then the rotational speed and deflection angle of each wheel are calculated according to formula (1)-formula (4), and the update frequency of 20 frames per second is sent to the driver of each motor through the CAN bus to control the robot to complete the specified motion. The actual rotational speed and deflection angle of each wheel are read at the same frequency, and the velocity of the robot body in the global coordinate system is obtained by the forward kinematics model of the robot. $V_{GA}$, is integrated to $v_{GA}$ to get the actual trajectory of the robot, and compared with the expected trajectory of the robot.

The forward kinematics model of the robot is shown in Formula (5):

$$v_{GA} = R(\theta)^{-1}v_R \quad (5)$$

Given the motion speed of the robot $v_G = [0.3,0,\pi/12]^T$, the rotational speed and deflection angle of each wheel of the robot can be obtained by formula (1)-formula (5) as follows: $\omega_0 = \omega_3 = 1216\text{r/min, } \omega_1 = \omega_2 = 1216\text{r/min, } \alpha_0 = -\alpha_3 = 11^\circ, \alpha_1 = -\alpha_2 = 17.5^\circ$. The results show that the rotation speed and deflection angle of each wheel of the robot can be obtained by formula (1)-formula (9). The walking trajectory of the robot is a circle with a radius of 1.146m, and the Oc coordinate of the rotation center is (01.146m). Under the above control variables, the trajectory of the robot is shown in figure 4.
Given the motion speed $v_G = [0.3,0.3,0]^T$ of the robot, the rotational speed and deflection angle of each wheel of the robot can be obtained by formula (1)-formula (5): $\omega_0 = \omega_1 = \omega_2 = \omega_3 = 1361 \text{r/min}$, $\alpha_0 = \alpha_1 = -\alpha_2 = -\alpha_3 = 45^\circ$. The walking trajectory of the robot is a straight line, and the angle between the walking track and the x-axis is $45^\circ$. Under the above control variables, the trajectory of the robot is shown in figure 5.

![Figure 5 Robot trajectory in parallel moving mode](image)

Through the above tests, the measured trajectory of the robot is consistent with the desired trajectory, which proves that the robot motion control system and control algorithm are correct and effective.

6. Conclusion

In view of the shortcomings of existing genetic algorithms in solving path planning problems, such as slow convergence and easy to fall into local optimization, a robot path planning method based on adaptive genetic algorithm is proposed. In this method, the inversion operator is introduced, the insertion operator and deletion operator are added, and the adaptive strategy is used to adjust the probability of crossover and mutation, which can effectively improve the convergence speed and reduce the possibility of falling into local optimization. The algorithm is verified by examples in MATLAB and Inte3D systems, and the results show that the improved adaptive genetic algorithm is more effective than the traditional genetic algorithm and the improved genetic algorithm. Considering that the layout of the equipment in the production workshop is relatively fixed in the actual project, the motion trajectory planning of the AGV robot is usually completed in the simulation link of the process route planning, and the digital twin technology is used to compare and analyze the simulation path and the actual physical path to realize the scheduling and monitoring of the AGV robot. Engineering application verification shows that the improved adaptive genetic algorithm can meet the needs of workshop AGV robot planning simulation.

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