Simulation of Automatic Wheel Speed Control Method for High Speed Wheeled Mobile Robot

Hua Li[1], Guo Li[2]

[1]School of Electronics and Internet of Things, Sichuan Vocational College of Information Technology, Sichuan, Guangyuan, 628017, China

[2]Chengdu Sino Microelectronics Technology Co.,Ltd., Sichuan, Chengdu, 610041, China

Keywords: Wheeled mobile machine; Automatic wheel speed control; Trajectory tracking

Abstract: Trajectory tracking of mobile robot refers to tracking a pre-planned curve trajectory as a function of time, which is a very complicated problem in motion control. Mobile robot is a kind of robot that can move and work autonomously or semi-autonomously with certain intelligence. It can complete the tasks planned by people in advance in the specified workplace. The traditional control scheme requires high accuracy of dynamic modeling of mobile robot, and is affected by the unstable ground adhesion. Smooth approximation and convergence speed are two important factors for trajectory tracking. In order to solve the plane motion control problem of wheeled mobile robot, the plane geometry theory is applied to trajectory tracking control. In this paper, based on the control law of high-speed wheeled mobile robot, aiming at the nonlinear and strong coupling characteristics of its control system model, an automatic control method of wheel speed of high-speed wheeled mobile robot based on adaptive control algorithm is proposed to realize the trajectory tracking and motion control of the robot.

1. Introduction

The emergence and development of robot technology not only fundamentally changes the traditional industrial production, but also has a far-reaching impact on human social life. Trajectory tracking of mobile robot refers to tracking a pre-planned curve trajectory as a function of time, which is a very complicated problem in motion control [1]. Because of the expansion of robot application from manufacturing to non-manufacturing, and the mobile robot has a very wide application prospect in such operations as field work, deep-sea exploration and some toxic or high-temperature environments that humans themselves can't enter [2]. The mobile robot involves the precise control of speed and steering, and the precise control of the actuator is affected by the accumulation of feedback errors and disturbances when the robot moves [3]. Compared with traditional industrial robots, wheeled mobile robots have stronger flexibility and larger working space, so they have been widely used in various military and civil occasions [4]. The motion control of wheeled mobile robot is to control the speed and direction of the robot, so that the robot can move along the predetermined trajectory and speed [5]. Trajectory tracking of mobile robot is a nonlinear problem, and it is very difficult to study this problem because the reference trajectory tracked by robot is directly related to time factors.

The traditional control scheme requires high accuracy of dynamic modeling of mobile robot, and is affected by the unstable ground adhesion [6]. Mobile robot is a kind of autonomous or semi-autonomous robot that can move and has certain intelligence. It can complete the tasks planned by people in advance in the specified workplace, and it is an important branch of robotics. If all kinds of sensors are applied to the wheeled mobile robot with wide workspace, so that it has the functions of exploring, learning, monitoring and autonomous decision-making in the unknown complex environment, then the wheeled mobile robot can complete all kinds of dangerous tasks [7]. Kim et al. linearly approximated the friction between the wheel and the ground, established the kinematics model of the wheeled sliding steering mobile robot, and realized the asymptotically convergent trajectory tracking through the adaptive control method [8]. Ahmad et al. simplified the

Copyright © (2023) Francis Academic Press, UK **DOI: 10.25236/icmmct.2023.032**

kinematics model of wheeled sliding steering mobile robot and added additional theoretical state observers, and used sliding mode control method to avoid obvious tire sliding [9]. The traditional PID controller with lag-lead correction and manual adjustment can not meet the requirements of high precision control. Aiming at the nonlinear and strong coupling characteristics of the control system model of high-speed wheeled mobile robot, this paper proposes an automatic control method of wheel speed of high-speed wheeled mobile robot based on adaptive control algorithm.

2. Methodology

The mobile robot is a system with nonholonomic constraints. In practice, the yaw rate of the robot is a function of the speed of the tracks on both sides, and it is affected by the friction coefficient of the ground. Some state parameters are difficult to obtain directly, and designing a controller with adaptive function can effectively control the system with unknown parameters. When the robot's mass is large or its motion speed is fast, the kinematics model can't fully reflect the real situation of the robot's motion, so it is necessary to take the dynamics of the robot into account [10]. At the same time, during the long-term operation of the robot, due to the changeable working environment, the influence of friction, the aging of components and the changes of system parameters are inevitable.

Any mobile robot can't do without sensors. In order to have intelligent behavior, mobile robots must constantly perceive the external environment and make corresponding decision-making behaviors. According to the past fault states of the sensor and propeller of the wheel, the state equation of the wheel is obtained as follows:

$$\begin{cases} Z = CZ + f_a + u(D + D_F) \\ S = (A + A)Z + v \end{cases} \tag{1}$$

Among them, C represents the real-time state matrix of the wheel; D represents the control matrix of the wheel; D_F represents the control matrix of the thruster failure in the wheel; A represents the fault matrix of the wheel sensor; Z represents the overall state variable of the wheel; S represents the output of the sensor in the wheel; u represents the control signal of the wheel; f_a represents the nonlinear term. After discretizing it, the state equation of the wheel can be obtained, and its expression is:

$$\begin{cases} Z_{k+1} = \phi Z_k + \Gamma(\beta_k)u_k + R_k \\ S_k = L(\beta_k)Z_k + T_k(\beta_k) \end{cases} \tag{2}$$

In the formula, Z_{k+1} and S_k both represent the state variable and output after discretization; ϕ represents the control variable coefficient; Γ represents the parameter after discretization; R_k represents the nonlinear term after discretization; β_k represents the discretization The fault control matrix of ; L and T_k both represent matrix coefficients.

The auxiliary speed controller of the robot kinematics model, the speed controller of the speed of the driving wheels on both sides based on the robot dynamics model and the on-line regulator of the sliding parameters. This method ensures the stability of the system by designing a control law that satisfies the boundedness and convergence of the system trajectory. The trajectory tracking control and kinematics controller of the mobile robot are designed to ensure that the mobile robot moves according to the predetermined trajectory. External sensors are used to detect the environment and condition of the robot, such as the camera used to capture environmental information, the ultrasonic sensor, infrared sensor and magnetic compass used to detect the current obstacle distance.

According to the state equation of the wheel, the equivalent model of the wheel is constructed, and the parameter vector of the wheel model is obtained by continuously training the filter model.

Firstly, the output signal of the wheel is calculated:

$$g(k)=\sum_{i=1}^{N} C_{iou}(1+k-i) \tag{3}$$

In the formula, $g(k)$ represents the output of the adaptive filter in the wheel, and N represents the order of the filter. Then the calculation formula of the difference signal is obtained as:

$$q(k)=g(k)-p(k) \tag{4}$$

In the formula, $q(k)$ represents the state error of the adaptive filter in the process of tracking and controlling the fault, and $p(k)$ represents the state of the wheel sensor.

The auxiliary speed controller gives the control parameters that can realize the gradual convergence of the tracking error of the moving trajectory. Then, the slip parameters of each wheel are estimated online by the slip parameter online regulator. Finally, the speed controller based on the dynamic model of the mobile robot controls the speed of the driving wheels on both sides according to the auxiliary speed control and slip parameters. Considering that the kinematics model can't fully reflect the real situation of the mobile robot with large mass or fast motion speed, this chapter further describes the motion essence of the robot more objectively and completely by establishing a dynamic model containing road friction information.

3. Result analysis and discussion

The accuracy of fuzzy control will depend on whether the fuzzy control rule set is complete and detailed. Fuzzy control does not need to establish a mathematical model, and can express complex nonlinear systems linguistically. It is a control system based on non-mathematical models, and it has been widely used in modern control systems. Because of the inherent nonlinear characteristics of the kinematic model of the mobile robot, it is often a very complicated problem to estimate the sliding parameters of the robot. The usual method is to use linear estimator to estimate the sliding parameters, which requires linearization of the kinematics model of the robot, which usually brings great errors. In practical application, it is difficult to obtain an accurate and complete system model because of inaccurate measurement and modeling, time-varying parameters and load disturbance, so the feedback control based on accurate model often cannot achieve the high performance that theoretical analysis should have. In order to verify the fault-tolerant control performance of this method, experiments are now carried out. The comparison results of anti-interference ability of different methods are shown in Figure 1.

Compared with the other two algorithms, the control error of the proposed method is the smallest. This result verifies that this method is a better fault-tolerant control method for robot wheel speed. According to the results, it can be seen that the actual trajectory of the mobile robot is close to the expected trajectory, the overshoot is small and the steady-state error is small under the control of the trajectory tracking control algorithm with online estimation of sliding parameters.

When using fuzzy control method to solve control problems, we don't strictly analyze the nonlinear factors in the control system and the influence on the control from the mathematical point of view, but more analyze the possible situations in the control, seek the general solution according to the controller's experience and transcendental knowledge, and then embody it in the form of fuzzy control rule set. Through experiments, the accuracy results obtained according to different algorithms are shown in Figure 2.

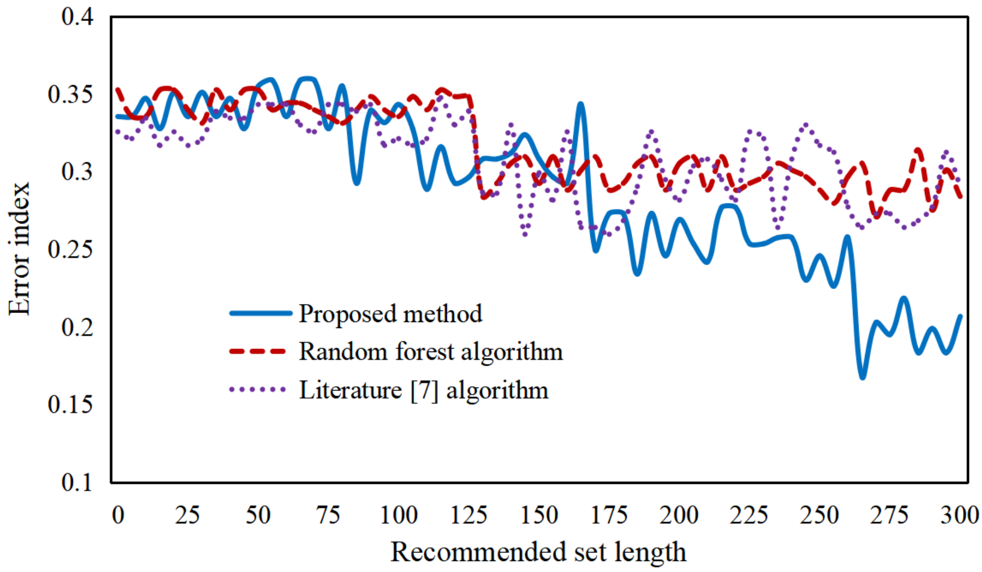

Figure 1 Comparison of anti-interference ability of different methods

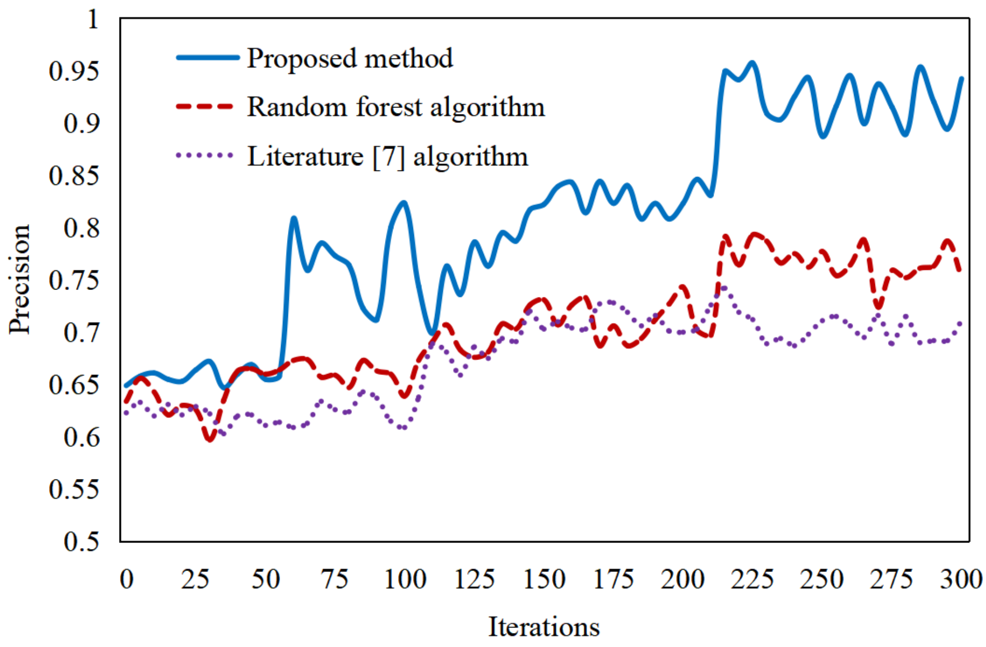

Figure 2 Accuracy of the algorithm

The measured data from inertial sensors contain a lot of noise, which requires the observer to be robust to noise and model uncertainty. At the same time, for the sliding mode observer, the control function is frequently switched in a limited time, which is bound to cause chattering. In order to avoid the influence of chattering on the system performance, the estimated value of the output of discontinuous sliding mode observer can be passed through a low-pass filter. The proposed method constructs an adaptive model for the wheel speed of the high-speed wheeled mobile robot, and obtains the parameter vector in the wheel speed control system of the robot to ensure the reliability of the control, so as to enhance the overall performance of the model.

4. Conclusions

Trajectory tracking of mobile robot is a nonlinear problem, and it is very difficult to study this problem because the reference trajectory tracked by robot is directly and closely related to time factors. The traditional control scheme requires high accuracy of dynamic modeling of mobile robot, and is affected by the unstable ground adhesion. Different from the traditional wheeled mobile robot control, the motion control system of wheeled mobile robot in complex environment presents its own characteristics and difficulties, mainly in that the uncertainty of the system and environmental interference will have a greater impact on the performance of the robot control system. Aiming at the nonlinear and strong coupling characteristics of the control system model of high-speed wheeled mobile robot, this paper proposes an automatic control method of wheel speed of high-speed wheeled mobile robot based on adaptive control algorithm. The proposed method constructs an adaptive model for the wheel speed of the high-speed wheeled mobile robot, and obtains the parameter vector in the wheel speed control system of the robot to ensure the reliability of the control, so as to enhance the overall performance of the model. Under the constraints of speed and acceleration, the rapidity of path tracking is realized by minimizing the number of control steps. Through mathematical iterative transformation, the analytical expression of speed difference control quantity is derived to improve the real-time performance of control algorithm.

References

[1] Juang C F, Lai M G, Zeng W T. Evolutionary Fuzzy Control and Navigation for Two Wheeled Robots Cooperatively Carrying an Object in Unknown Environments.[J]. IEEE Transactions on Cybernetics, 2017, 45(9):1731-1743.

[2] Joonyoung, Kim. Trajectory Generation of a Two-Wheeled Mobile Robot in an Uncertain Environment[J]. IEEE Transactions on Industrial Electronics, 2019, 67(7):5586-5594.

[3] Fareh R, Baziyad M, Rahman M H, et al. Investigating Reduced Path Planning Strategy for Differential Wheeled Mobile Robot[J]. Robotica, 2019, 38(2):235-255.

[4] Mirzaeinejad H, Shafei A M. Modeling and trajectory tracking control of a two-wheeled mobile robot: Gibbs–Appell and prediction-based approaches[J]. Robotica, 2018, 36(10):1551-1570.

[5] Lu P, Yu W, Chen G, et al. Leaderless Consensus of Ring-Networked Mobile Robots via Distributed Saturated Control[J]. IEEE Transactions on Industrial Electronics, 2020, 67(12):10723-10731.

[6] Shu, Ding, Liang, et al. Adaptive neural network tracking control-based reinforcement learning for wheeled mobile robots with skidding and slipping[J]. Neurocomputing, 2018, 283(3):20-30.

[7] Mahmoud M S, Nasir M T. Robust Control Design of Wheeled Inverted Pendulum Assistant Robot[J]. IEEE/CAA Journal of Automatica Sinica, 2017, 2017(04):55-65.

[8] Kim Y, Kook K B. Time-Optimal Trajectory Planning Based on Dynamics for Differential-Wheeled Mobile Robots With a Geometric Corridor[J]. IEEE Transactions on Industrial Electronics, 2017, 64(99):5502-5512.

[9] Ahmad N S. Robust H. Fuzzy Logic Control for Enhanced Tracking Performance of a Wheeled Mobile Robot in the Presence of Uncertain Nonlinear Perturbations[J]. Sensors, 2020, 20(13):3673.

[10] Juman M A, Wong Y W, Rajkumar R K, et al. An incremental unsupervised learning based trajectory controller for a 4 wheeled skid steer mobile robot[J]. Engineering Applications of Artificial Intelligence, 2019, 85(Oct.):385-392.