

Smooth Sliding Mode Control for Trajectory Tracking of Greenhouse Spraying Mobile Robot

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Abstract

For the spraying mobile robot working in greenhouse, due to the inconsistency of drive motors and the rough walking surface, it is easy to track off. For the liquidity of pesticide, the load always changes even the speed jumps. Because of these uncertainties, external disturbances and the difficulty of constructing the system dynamic model, it is hard to implement the trajectory tracking control of the spraying mobile robot steadily, precisely and quickly. In order to solve the problem, a smooth sliding mode trajectory tracking control method is proposed based on the distribute control strategy for each branch. Moreover, its stability is proved using the Lyapunov function. The simulation results show that the proposed method can track the reference trajectories precisely, quickly and steadily under the strong white noise. The chattering phenomenon of the control law is restrained compared to the conventional sliding mode control. The trajectory tracking performance is better than that of the fuzzy control. The designed method is easy to realize and doesn't need to construct the precise mathematical model, so, it affords an economical and convenient control method for solving the trajectory tracking problem of the greenhouse spraying mobile robot under various uncertain interferences.

Keywords: Smooth sliding mode control, trajectory tracking, mobile robot, greenhouse spraying

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1. Introduction

At present, more than 90% spraying machineries are hand-operated. In this extensive spraying way, the utilization rate of pesticide is low and the environment is polluted. Greenhouse environment is high temperature, high humidity, relatively closed, and easy to cause the spraying operator poisoned [1]. Thus, there is an urgent need to research mobile robot and apply it to spray automatically and effectively in greenhouse. Generally, the greenhouse inter-row of crops is rough soil ground. It is need to solve the off tracking problem caused by inconsistency of drive motor and rough ground for the robot working in greenhouse crop rows. Meanwhile, during the starting, stopping and turning process of robot, the fluidity of liquid pesticide will results in the robot's linear and angular velocities fluctuations. Further, the steady-state performance and dynamic quality of trajectory tracking controller are tremendously affected. Especially, the speed jump problem may cause mobile robot instable [2].

For the speed jump problem of conventional robot, a fuzzy control method, which takes the deviation both X-axles distance and direction as input, is designed to control the rotate speed of two wheels in [3], while it does not take the deviation of Y-axles into consideration, so it appears obviously fluctuation when tracking curve trajectory. A controller setting the velocity error and the velocity error rate as inputs is proposed in [4], it adjusts the output power of drive motor to control robot's speed through judging the input data by fuzzy rules, however, the control effect of the method is greatly determined by the fuzzy rules division and there exists stable-state error. A method combining the fuzzy algorithm and PID is put forward in [5], it uses the fuzzy control unit to afford real-time gain regulation for PID control, as a result, the interference of controller from rough ground is reduced, but there exists speed jump problem. In order to weaken the fluctuation of linear and angular velocities, an neural network method is proposed to smooth the speed control signal for mobile robot in [6], but the training samples are difficult to get as the speed jump unpredictable.

For the spraying robot which is walking as it sprayed in greenhouse, the linear and angular displacement are fluctuating continuously caused by changing load, as a result, it is

difficult for greenhouse spraying robot control system to construct the accurate mathematical model and confirm the system parameters effectively, at the same time, there are the unmodeled dynamic error, the measurement noise and the uncertainly external interference etc, it brings great difficulties for the greenhouse mobile robot to achieve trajectory tracking control quickly and precisely. The fuzzy control method does not require the accurate mathematical model of control object, thus, it is adaptive and flexible, but the fuzzy rules can't induct perfectly and self-learning, which leads to the control precision lower and the stable-state error more difficult to reach an ideal level. The prerequisite of the neural network overcoming the unmodeled interference and the uncertainties of greenhouse spraying mobile robot trajectory tracking system is getting the barely accessible training samples, if adopting online learning, the time will be longer, which cannot meet the real-time requirement of greenhouse spraying mobile robot.

In order to overcome the effects of the spraying mobile robot trajectory tracking control in greenhouse, a smooth sliding mode control method is proposed in this paper. The designed method has a series of advantages, such as fast response, simple to carry out, not require on-line identification, and insensitive to the change of controlled object parameters and environment. It can eliminate external disturbances and implement the trajectory tracking motion control precisely, quickly and steadily for the spraying mobile robot working in complex greenhouse environment.

2. Description of The Problem

This paper is based on AS-R robot, which consists of two wheels drive independently and a balanced wheel. The rear-wheel is driven by coreless and brushless DC servo motor. The robot structure is shown in Figure 1, assume that the midpoint of driving wheel axle $M(x, y)$ is the center of robot, θ (counterclockwise is positive) denotes the angle between the advance direction of robot and X-axis, $2r$ denotes the drive wheels diameter, $2b$ denotes the rear-wheel axle length, $p = (x \ y \ \theta)^T$ denotes the posture of the robot.

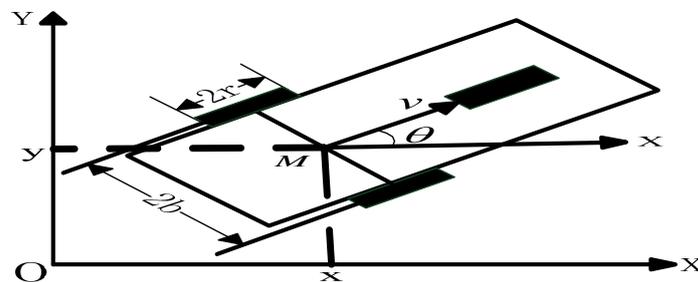


Figure 1. Schematic Diagram of Mobile Robots

The linear and angular velocity of mobile robot expressed by v and ω . So, the robot kinematics equation is presented as:

$$p = \begin{bmatrix} \dot{x} \\ \dot{y} \\ \dot{\theta} \end{bmatrix} = \begin{bmatrix} \cos \theta & 0 \\ \sin \theta & 0 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} v \\ \omega \end{bmatrix} \quad (1)$$

The structure of the trajectory tracking error system is shown in Figure 2. M denotes the current position of robot, coordinate for $p_c = (x_c \ y_c \ \theta_c)^T$, M_r denotes the desired position, coordinate for $p_r = (x_r \ y_r \ \theta_r)^T$, $p_e = (x_e \ y_e \ \theta_e)^T$ denotes the error between the desired position and current, θ_e denotes the navigation angle. By analyzing Figure 2, the geometric relationships can be derived as:

$$p_e = \begin{bmatrix} x_e \\ y_e \\ \theta_e \end{bmatrix} = \begin{bmatrix} \cos\theta_c & \sin\theta_c & 0 \\ -\sin\theta_c & \cos\theta_c & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x_r - x_c \\ y_r - y_c \\ \theta_r - \theta_c \end{bmatrix} \quad (2)$$

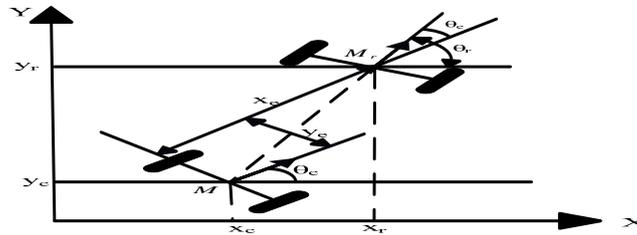


Figure 2. Mobile Robots Trajectory Tracking Error Model

The trajectory tracking of mobile robot based on kinematics model is looking for the bounded input $q = [v \ \omega]^T$, in any initial posture, to make the error vector $p_e = (x_e \ y_e \ \theta_e)^T$ bounded and $\lim_{t \rightarrow \infty} \|x_e \ y_e \ \theta_e\|^T = 0$.

3. Smooth Sliding Mode Control Design

In order to solve the precision and stability problem of trajectory tracking for spraying mobile robot walking on the rough surface in the crops inter-row, a completely chattering-free sliding mode controller is designed. Taking the advantage of decoupling during designing the sliding mode control method to construct the system based on decentralized control of each drive branch, which is not only convenient to improve the precise control but also easy to design and implement.

Construct the greenhouse spraying mobile robot control system block diagram, as shown in Figure 3, the desired posture of mobile robot is transformed into the desired angular displacements of left and right drive motors by inverse kinematics analysis, after that, the angular deviation between the desired angular displacement and actual obtained from drive motor encoder is taken as the input of controller, then the control voltage of drive motor is taken as the output, by controlling the left and right drive wheels to track desired angular displacement to achieve the greenhouse spraying mobile robot trajectory tracking. In Figure 3, $\theta'_{d1}, \theta'_{d2}$ denote respectively the desired angular displacements of left and right drive motors, u_1, u_2 denote respectively the control voltages of left and right drive motors, θ_1, θ_2 denote respectively the real angular displacements of left and right drive motors.

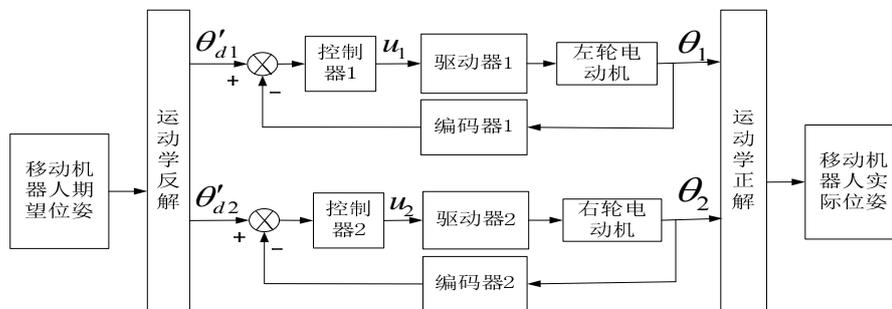


Figure 3. Mobile Robot Control System Diagram

3.1. Inverse Kinematics Analysis of Mobile Robot

The aim of reverse kinematics is to obtain the desired angular displacement of left and right drive motors based on the desired position and direction of mobile robot. In detail, under the condition that the midpoint of rear-wheels axle coordinate $M(x, y)$ and the angle θ_r between forward direction and X-axis are known, the drive motor desired angular displacements $\theta'_{d1}, \theta'_{d2}$ can be derived. In order to meet the inverse kinematics analysis requirements, a global coordinate system XOY and a local coordinate system X_RMY_R are built.

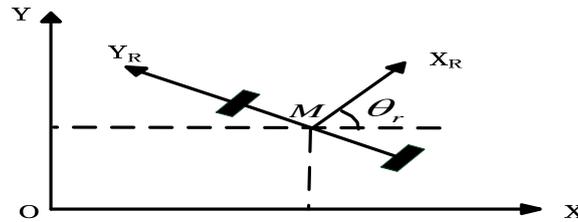


Figure 4. Local and global coordinate system of mobile robot

In Figure 4, θ_c denotes the subtract between local and global coordinate system, assume that the middle point of axle M is the origin of local coordinate system, $\zeta^R = [x, y, \theta_r]^T$ denotes the mobile robot posture at global coordinate system, $\zeta' = [x', y', \theta']$ denotes the mobile robot posture at local coordinate system. The relation between ζ^R and ζ' is $\zeta' = R(\theta_c)\zeta^R$ [7], where $R(\theta_c)$ (orthogonal property of rotation matrices) is presented as:

$$R(\theta_c) = \begin{bmatrix} \cos \theta_c & \sin \theta_c & 0 \\ -\sin \theta_c & \cos \theta_c & 0 \\ 0 & 0 & 1 \end{bmatrix} \tag{3}$$

The local coordinate system is shown in Figure 5,  is the mapping of , x' denotes the displacement of X-axis, whereas, y' denotes Y-axis, θ' (counter clockwise is positive) is equivalent to the navigation angle θ_c , O' is the instantaneous turning center of mobile robot, ρ is the turning radius,  and L_2 are the left and right wheels desired displacements.

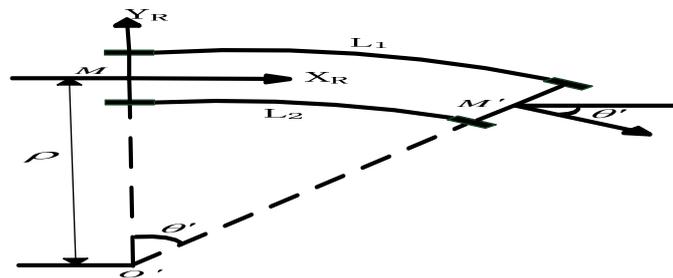


Figure 5. Local coordinate system of the mobile robot

The relation between global and local coordinate system can be expressed as:

$$\begin{bmatrix} x' \\ y' \\ \theta' \end{bmatrix} = \begin{bmatrix} \cos \theta_c & \sin \theta_c & 0 \\ -\sin \theta_c & \cos \theta_c & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x_r \\ y_r \\ \theta_r \end{bmatrix} \tag{4}$$

The geometric relation can be written as:

$$\rho = \frac{\sqrt{x'^2 + y'^2} / 2}{\sin(\theta'/2)} \quad (5)$$

The desired displacements of left and right wheels can be expressed as:

$$L_1 = \theta'(\rho - b) \quad (6)$$

$$L_2 = \theta'(\rho + b) \quad (7)$$

In Equation 6 and Equation 7, b is the half of two wheel axial length.

The next step is calculating the angular displacements of drive motors in the condition of knowing the drive wheels displacement. Assume that, θ'_{di} denote the desired angular displacement of left and right drive motor respectively. n_1, n_2 denote the desired turning laps of the wheels and the drive motor respectively when the displacement of wheels is L_i ($i=1,2$), so, the physical relation can be expressed as $L_i = 2\pi \cdot n_i$, where, r is the radius of rear-wheel. Because of the wheel and the drive motor is coaxial rotating, so n_1 equal to n_2 . So the desired angular displacement of drive motor can be derived as:

$$\theta'_{di} = 2\pi \cdot n_i = \frac{L_i}{r}, \quad i=1,2 \quad (8)$$

According to Equation 4, Equation 6, Equation 7, Equation 8, the matrix form can be expressed as:

$$\begin{bmatrix} \theta'_{d1} \\ \theta'_{d2} \end{bmatrix} = \frac{\theta'}{r} \begin{bmatrix} 1 & -1 \\ 1 & 1 \end{bmatrix} \begin{bmatrix} \rho \\ b \end{bmatrix} \quad (9)$$

In Equation 9, θ'_{di} can be derived from x_r, y_r, θ_r, r, b

Considering Equation 6 and Equation 7, when $\theta' > 0$, that is $L_1 > L_2$, so the robot turns right, when $\theta' < 0$, that is $L_1 < L_2$, so robot turns left, when $\theta' = 0$, Equation 9 can be rewritten as

$\theta'_{di} = \frac{\theta'}{r}(\rho \pm b)$, then substituting Equation 5 into Equation 9, the result is expressed as:

$$\theta'_{di} = \lim_{\theta' \rightarrow 0} \frac{\theta'}{r}(\rho \pm b) = \frac{\theta'}{r} * \rho = \frac{\theta'}{r} * \left(\frac{\sqrt{x'^2 + y'^2} / 2}{\sin(\theta'/2)} \pm b \right) = \frac{\theta'/2}{\sin(\theta'/2)} * \frac{\sqrt{x'^2 + y'^2}}{r} = \frac{\sqrt{x'^2 + y'^2}}{r}$$

Clearly, the robot walks along straight. So the analysis of inverse kinematics is completed.

3.2. Kinematics Positive Analysis of Mobile Robot

The aim of kinematics positive analysis is to obtain the posture of the mobile robot in global coordinate system, in the case of knowing the left and right drive motor real angular displacement. Assume that, θ_1, θ_2 denote the actual angular displacements of left and right drive motors respectively, which get from motor encoder. Because of driving motor and wheels are co-axial, so the angular velocity of the wheel equals to the drive motor angular velocity. $\omega_1,$

ω_2 denote the left and right motor angular velocity. The relation between ω and θ is $\omega_1 = \frac{d\theta_1}{dt},$

$\omega_2 = \frac{d\theta_2}{dt}$. As reference [8] shows, the relationship between linear and angular velocity of robot and left and right drive motor angular velocity is:

$$\begin{bmatrix} v \\ \omega \end{bmatrix} = \begin{bmatrix} \frac{r}{2} & \frac{r}{2} \\ \frac{r}{2b} & -\frac{r}{2b} \end{bmatrix} \begin{bmatrix} \omega_1 \\ \omega_2 \end{bmatrix} \quad (10)$$

Substituting Equation 20 into Equation 1, then mobile robot posture in the global coordinate system can be derived.

3.3. The Design of Smooth Sliding Control

The drive motor of mobile robot is dc-servo motor. Taking the angular $\theta(s)$ and the voltage $U(s)$ of the driving shaft as its input and output, the transfer function can be written as:

$$G(s) = \frac{\theta(s)}{U(s)} = \frac{K_t}{s(L_a s + R_a)(Js + B) + K_t K_e s} \quad (11)$$

Where, $U(s)$ is the Laplace transformation of the controller output $u(V)$, $\theta(s)$ is the Laplace transformation of the drive motor's angular displacement $\theta_i(\text{rad})$, R_a is armature resistance(Ω), L_a is armature inductance(mH), B is viscous damping coefficient($\text{N}\cdot\text{m}(\text{rad/s})$), J is moment of inertia($\text{kg}\cdot\text{m}^2$), K_e is the coefficient of anti-electromotive force($\text{V}(\text{rad/s})$), K_t is motor torque constant($\text{N}\cdot\text{m/A}$).

The conventional sliding mode control law is expressed as:

$$u = u_{eq} + \beta \text{sgn}(s) \quad (12)$$

Where, u_{eq} is the control term in the situation of ignoring the system uncertainty and disturbance, $\beta \text{sgn}(s)$ is a switch control for the uncertain part of the control system. An idea to design sliding mode control can be described as: taking the distance from the system state to the sliding surface, that is, the smooth sliding function replaces the sign function $\text{sgn}(s)$ [9]. The change of the sign is actually the same as the original sign function, but its control law is composed by a continuous function.

Based on the dc-servo drive motor mathematic model of greenhouse mobile robot, a smooth sliding mode control law can be designed as:

$$u = u_{eq} + \gamma s \quad (13)$$

Where u_{eq} is the equivalent control term, s is a predefined sliding function, γ is a positive number.

Construct the sliding surface as:

$$s = \ddot{e} + c_1 \dot{e} + c_2 e = 0 \quad (14)$$

Where $e = \theta'_{di} - \theta_i$, θ_i denotes the actual movement angular displacement of the wheels drive motor, θ'_{di} denotes the desired movement angular displacement of the wheels drive motor, \dot{e} denotes the first derivative of e , \ddot{e} denotes the second derivation of e . According to the Routh criterion, only $c_1 > 0$ and $c_2 > 0$, then the sliding motion is stable. Once system reaches to sliding surface, the performance is totally determined by s . According to the system performance requirements to assign poles of sliding surface, the ranges of c_1 and c_2 are determined. On the basis of sliding mode control characteristics, the accurate model of object is not required, and the ranges of parameters are only needed. According to the sliding requirement $s\dot{s} \leq -\eta|s|$ and system state equation, the ranges of parameters c_1 , c_2 , γ can be determined.

The state space equation of Equation 11 can be rewritten as:

$$\begin{cases} x_1 = \theta \\ x_2 = \dot{\theta} = \dot{x}_1 \\ x_3 = \ddot{\theta} = \ddot{x}_2 \end{cases} \quad (15)$$

$$\dot{x} = Ax + Cu \quad (16)$$

Then the vector-matrix of Equation 15, Equation 16 can be expressed as:

$$\begin{bmatrix} \dot{x}_1 \\ \dot{x}_2 \\ \dot{x}_3 \end{bmatrix} = \begin{bmatrix} 0 & 1 & 0 \\ 0 & 0 & 1 \\ 0 & -A_3/A_1 & -A_2/A_1 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ C/A_1 \end{bmatrix} u \quad (17)$$

where $A_1 = L_a J$, $A_2 = L_a B + R_a J$, $A_3 = R_a B + K_t K_e$, $C = K_t$. θ denotes the actual angular displacement of the motor; e denotes the motor angular displacement error, \dot{e} denotes the angular velocity error, \ddot{e} denotes the angular acceleration error. Take e , \dot{e} , \ddot{e} as the state variables, Equation 15 can be rewritten as:

$$\begin{cases} e = \theta - x_1 \\ e_1 = \dot{e} = \dot{\theta} - x_2 \\ e_2 = \ddot{e} = \ddot{\theta} - x_3 \end{cases} \quad (18)$$

If ignoring the system parameters variation and disturbance, the control term u equals to u_{eq} , when $\dot{s} = 0$, where u_{eq} is used to maintain sliding mode motion. From Equation 14, Equation 17, Equation 18, u_{eq} can be derived as:

$$u_{eq} = \frac{A_1}{C} \ddot{\theta}'_{di} + \frac{A_2}{C} \dot{\theta}'_{di} + \frac{A_3}{C} \theta'_{di} + \frac{A_1 c_1 - A_2}{C} \ddot{e}_i + \frac{A_1 c_2 - A_3}{C} \dot{e}_i \quad (19)$$

The smooth sliding mode control law is designed as:

$$u_i = \frac{A_1}{C} \ddot{\theta}'_{di} + \frac{A_2}{C} \dot{\theta}'_{di} + \frac{A_3}{C} \theta'_{di} + \frac{A_1 c_1 - A_2}{C} \ddot{e}_i + \frac{A_1 c_2 - A_3}{C} \dot{e}_i + \gamma s \quad (20)$$

In Equation 19, Equation 20, θ'_{di} ($i=1,2$) denotes the desired movement angular displacement of drive motor. In Equation 20, the term γs is used to suppress various uncertainty disturbance when mobile robot moving. The system stability is proved with the Lyapunov function as follows:

$$\text{Define Lyapunov function: } V = \frac{1}{2} s^2$$

$$\text{From Equation 14, it is can be derived as: } \dot{s} = \ddot{e} + c_1 \dot{e} + c_2 e$$

Then, $\dot{V} = s\dot{s} = (\ddot{e} + c_1 \dot{e} + c_2 e)s$, substitute Eq.14, Eq.17, Eq.18, Eq.20 into it, \dot{V} can be written as:

$$\dot{V} = c_1 \dot{\theta}'_{di} \cdot s + c_2 \theta'_{di} \cdot s + \frac{A_2 - A_1 c_1}{A_1} \ddot{\theta} \cdot s + \frac{A_3 - A_1 c_2}{A_1} \dot{\theta} \cdot s - \frac{A_2}{A_1} \ddot{\theta}'_{di} \cdot s - \frac{A_3}{A_1} \dot{\theta}'_{di} \cdot s - \frac{A_1 c_1 - A_2}{A_1} \ddot{\theta}'_{di} \cdot s + \frac{A_1 c_1 - A_2}{A_1} \dot{\theta}'_{di} \cdot s$$

$$-\frac{A_1 c_2 - A_3}{A_1} \dot{\theta}'_{di} \cdot s + \frac{A_1 c_2 - A_3}{A_1} \dot{\theta} \cdot s - \gamma s^2 = -\gamma s^2$$

Since γ is positive and $s^2 \geq 0$, then $\dot{V} \leq 0$, so the system is proved to be stable.

4. System Simulation Experiment

In order to verify the effectiveness of the sliding mode control method designed in this paper for greenhouse mobile robot, linear and circle trajectory tracking simulations are carried out in MATLAB [10] under the white noise which stands for the various uncertainties interference when robot walking.

The researched robot is driven by two 70W DC servo motors, the deduction ratio is 33:1. According to the type of DC servo motor, the parameters in Equation 14 are $B=6.59 \times 10^{-6}$ N·m(rad/s), $L_a=0.1$ mH, $K_t=0.0255$ N·m/A, $J=0.062 \times 10^{-3}$ kg·m², $R_a=0.628$ Ω, $K_e=0.067$ V(rad/s), the radius of two rear-wheel axle and the wheels are $b=0.2$ m, $r=0.05$ m. Set the control parameters of Equation 20 as $c_1=6.5$, $c_2=25$, $\gamma=0.95$.

4.1. Tracking Straight Trajectory

Assume the greenhouse spraying mobile robot initial posture is $P(0)=[0,0,\pi/3]^T$, the desired trajectory is $y=1(x=0)$, and the white noise as $dt=100 \cdot \text{randn}(1,1)$, the simulation results are shown in Figure 6~Figure 9.

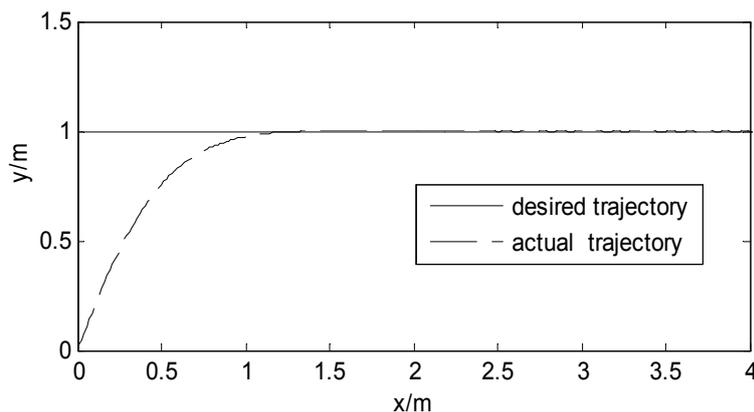


Figure 6. The Mobile Robot Tracking Straight Trajectory

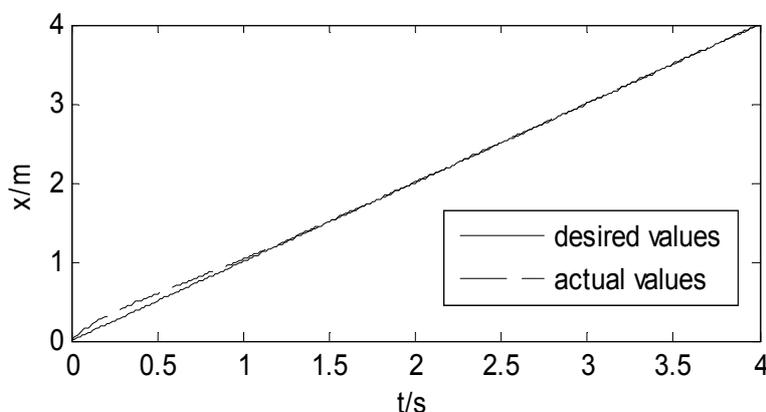


Figure 7. Straight Trajectory X-Axis Tracking

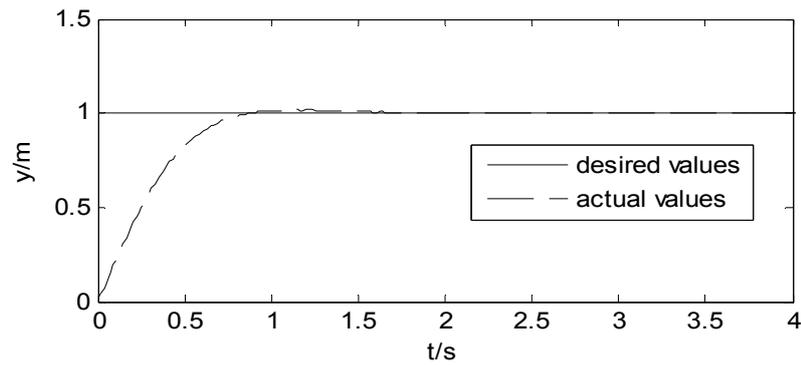


Figure 8. Straight Trajectory Y-Axis Tracking

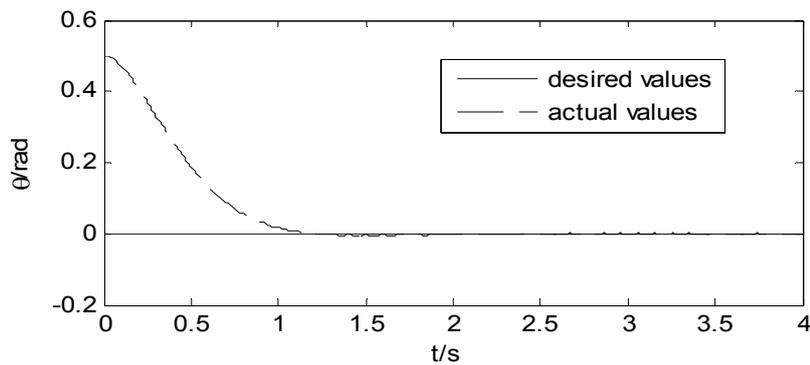
Figure 9. Straight trajectory θ direction tracking

Figure 6 shows the linear trajectory tracking, it is clear that the desired trajectory and actual trajectory are together after 1.5 s, the process of tracking is smooth and stable. Figure 7, Figure 8 and Figure 9 show the tracking results of X-axes, Y-axes and θ direction, it can be concluded that, the tracking error is small and the speed of converge is fast by using the proposed method to achieve the straight line trajectory tracking,

4.2. Tracking Curve Trajectory

Setting the initial posture of greenhouse spraying mobile robot as $P(0)=[0.5,0,\pi/12]^T$, the desired trajectory as $f(x,y)=x^2+y^2-1=0$, the center of circle trajectory as $(0,0)$, the white noise as $dt=1000*\sin(2*\pi*t)$. the simulations are shown in Figure 10~Figure 11.

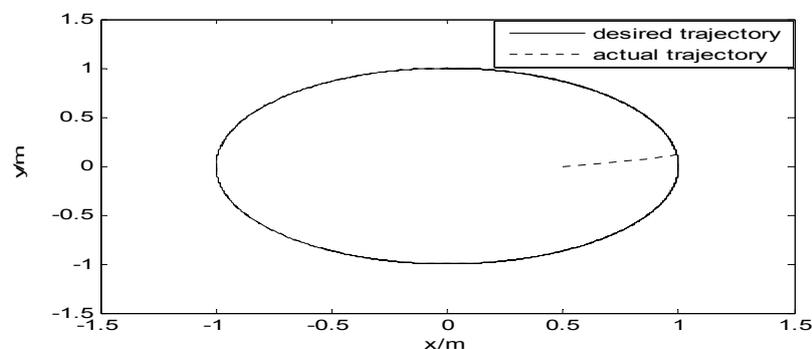


Figure 10. The Mobile Robot Circle Trajectory Tracking

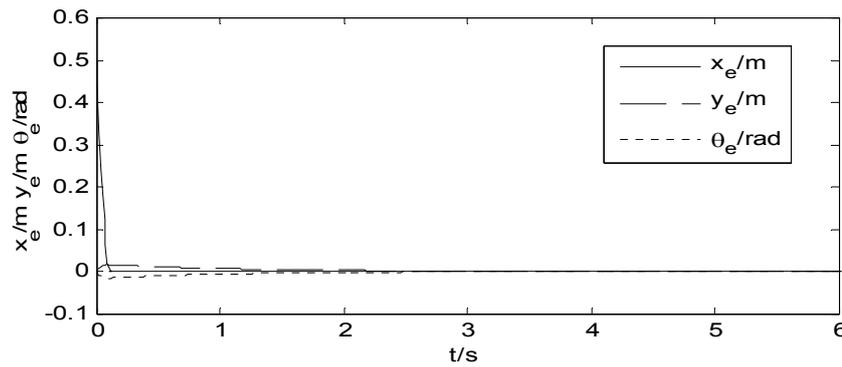


Figure 11. The mobile robot circle trajectory tracking errors

From Figure 10, it is clear that, the designed control method has a smooth and stable tracking course of circle trajectory and can achieve the accurate tracking. Figure 11 is the tracking error of X-axes, Y-axes and θ direction, it is shown that, the trajectory tracking process of greenhouse mobile robot is stable and can converge to zero quickly.

In order to further verify the effectiveness of the method, the contrasts with conventional sliding mode control and fuzzy control method are given.

Assume the initial posture of mobile robot is $P(0)=[2,0,-\pi/3]^T$, and desired curve trajectory is $r(t)=-2*t-2.5*\sin(0.5*\pi*t)$, the simulation results are shown in Figure 14, Figure 15.

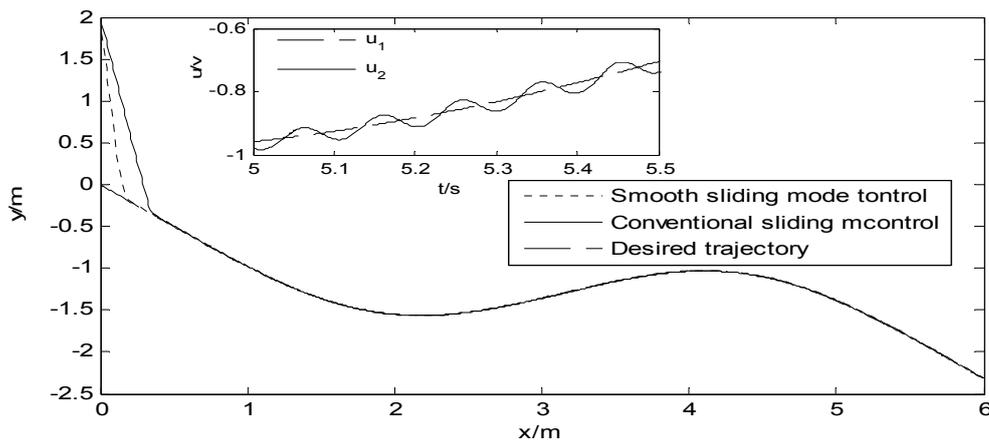


Figure 14. Curve Trajectory Tracking Comparison Between Smooth Sliding Mode and Conventional Sliding Mode

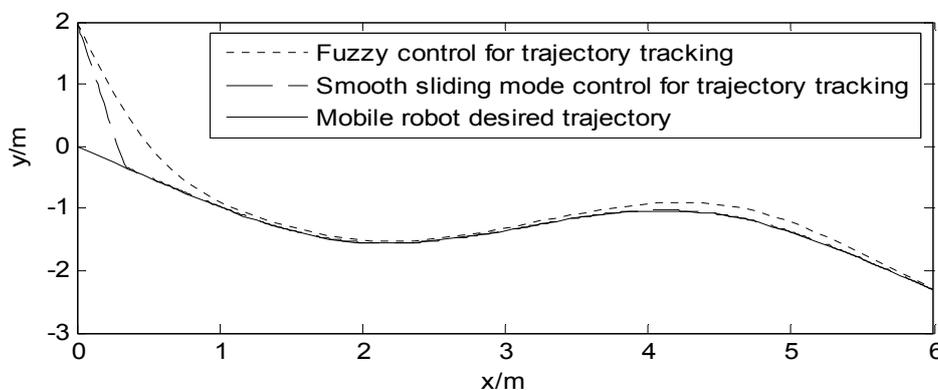


Figure 15. Curve Trajectory Tracking Comparison Between Smooth Sliding Mode and Fuzzy Control

As Figure 14 shown, the chattering problem of conventional sliding mode is eliminated by the smooth sliding mode control effectively. In Figure 15, it is clear that the steady-state error of fuzzy control is difficult to reach an ideal level, by the contrary, the smooth sliding mode control has a higher control precision and faster tracking speed.

A strong amplitude of white noise is added during the simulation, which used to simulate the various uncertainties disturbances, such as rough flat, speed jump etc., in the movement process of greenhouse mobile robot. From Figure 6~Figure 13, it is shown that, the proposed control method has a strong anti-interference capability, and can effectively overcome various uncertain interferences of greenhouse spraying mobile robot in walking and spraying, and also can achieve the trajectories tracking steadily, precisely and quickly.

5. Conclusion

For the spraying mobile robot working in greenhouse, due to the inconsistency of drive motors and the rough walking surface, it is easy to track off. For the liquidity of pesticide, the load always changes even the speed jumps. Because of these uncertainties, external disturbances and the difficulty of constructing the system dynamic model, it is hard to implement the trajectory tracking control of the spraying mobile robot steadily, precisely and quickly. In order to solve the problem, a smooth sliding mode trajectory tracking control method is proposed based on the decentralized control strategy for each branch.

The stability of the smooth sliding mode control is theoretically proved based on the Lyapunov function.

The simulation results show that the proposed method can track the reference trajectories precisely, quickly and steadily under the strong white noise. The chattering phenomenon of the control law is restrained compared to the conventional sliding mode control. The trajectory tracking performance is better than that of the fuzzy control.

For greenhouse spraying mobile robot, the designed method is easy to realize and doesn't need to construct the precise mathematical model, so, it affords an economical and convenient control method for solving the trajectory tracking problem of the greenhouse spraying mobile robot under various uncertain interferences.

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