TRACKING CONTROL OF THE COUPLING TRAILER BASED ON ADAPTIVE SLIDING MODE CONTROL

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ABSTRACT
An adaptive sliding mode control tracking algorithm is given for the mobile robot system with n-section tandem-axis trailer under the camera, Since the mobile robot system with the tandem-axis trailer can be converted into a type of uncertain chain system. First of all, the system is transformed into an uncertain chained system, and the error model is obtained, a switching controller is designed by designing two sliding surfaces, and the controller has been improved. The control law guarantees that all the state errors of the trailer system approach zero. Simulation results confirm the effectiveness of the proposed control law.

Keywords: *Shaft type; Trailer; Adaptive; Sliding mode control; Chained system.*

1. INTRODUCTION

Trailer mobile robot consists of a tractor and trailer composed of several sections, the tractor performs driving and steering tasks, and the trailer passively follows the tractor movement, such robot systems are typically used to automate factories, airports, railway stations, shipping docks, nuclear environment and so on, to perform material transport, baggage handling, cargo transport and other tasks.

The main control problem of mobile robot with trailer is path tracking control. The problem has become complicated by the presence of multiple bodywork. The mobile robot with trailer mainly includes the two types of the coupling trailer and the Off-axis trailer, and the Off-axis trailer cannot be converted into chain system, and the Linearization method is adopted or the virtual robot method is constructed. The paper [1] adopts the Linearization method and designs the discontinuous feedback controller for the forward tracking and reversing tracking of the line and the arc for the model Robot and the trailer system. In the paper [2], a virtual robot, which is located at the rear of the trailer and symmetrical with the tractor, is constructed for the system of the trailer, which realizes the tracking control of the original system by controlling the virtual robot. He Zhanbin and Ma Baoli transformed the kinematics equation of the Off-axis trailer mobile robot into a time-state model and designed a linear switched feedback stabilizing controller to ensure that the state of the robot converges to the small neighborhood of the origin in finite time [3]. The internal model principle of Zhou and Ma is used to design the linearization dynamic Feedback Control Law of the system, which ensures that the path tracking error is bounded and finally uniformly bounded [4]. In paper [5], the control problem of tracking any path at the midpoint of the axle with continuous time-varying and possibly changing sign is studied. The designed control law can realize the tracking of a given path by a trailer mobile robot. Because the coupling trailer system can be converted into a general chain system, we usually use the Lyapunov method to study it. In the paper [6], Samson transformed the system into an oblique symmetric chain system by coordinate and output transformations, the control law is designed to track the specified location. A local tracking controller with exponential convergence is proposed based on Lyapunov method by Astolfi, which is used for straight line and arc forward tracking control of this kind of robot [7]. The asymptotically convergent reversing tracking controller is designed for two-body systems based on Lyapunov method [8].

This paper mainly studies the tracking problem of the coupling trailer under the camera. Based on the adaptive sliding mode control, two sliding surfaces are designed, and the corresponding sliding mode variable structure controller is obtained for the chain system. The sliding mode control method is simpler and less computational than other methods, but the disadvantage is that it will cause unnecessary jitter. In this paper, the controller is improved for its jitter problem, and the jitter can be reduced appropriately.

2. KINEMATIC UNCERTAIN CHAIN SYSTEM MODEL OF THE COUPLING TRAILER SYSTEM

The coupling trailer system is mainly guided by a tractor and links the nonholonomic multiple-body system of multiple trailers. And each body is linked by a single shaft. Consider the N-section standard connection trailer robot system under the Monocular camera, as shown in Figure 1.

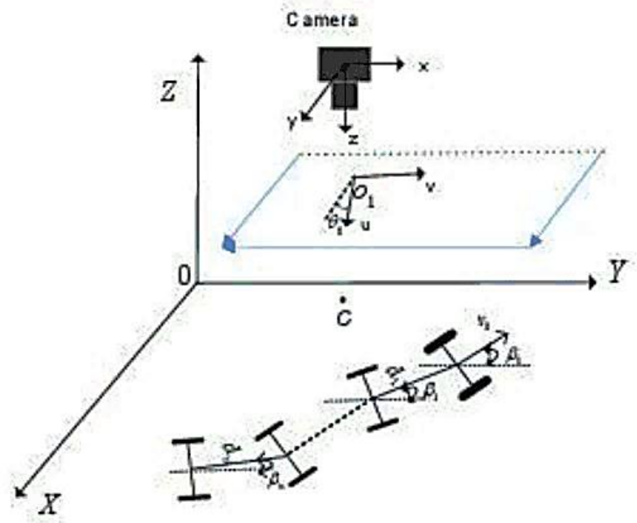


Fig. 1 The trailer system under the camera

As shown below, there is the kinematic equations of the N-section standard connection trailer robot system [9].

$$\begin{cases} \dot{x} = v_n \cos\beta_n, \\ \dot{y} = v_n \sin\beta_n, \\ \dot{\beta}_n = \dfrac{1}{d_n} v_{n-1} \sin(\beta_{n-1} - \beta_n), \\ \vdots \\ \dot{\beta}_i = \dfrac{1}{d_i} v_{i-1} \sin(\beta_{i-1} - \beta_i), \\ \vdots \\ \dot{\beta}_1 = \dfrac{1}{d_1} v_0 \sin(\beta_0 - \beta_1), \\ \dot{\beta}_0 = \omega. \end{cases} \tag{1}$$

Suppose the camera coordinates plane X-Y is the same as the image coordinate plane u-v. The point C is the intersection of the camera's optical axis and the plane X-Y, the coordinate in the plane X-Y is (c_x, c_y), the coordinate of the camera coordinate origin in the image coordinates is (O_{c1}, O_{c2}), the coordinate of the robot center of Mass in the plane X-Y is (x, y). v_0 is the speed of the tractor, v_i is the speed of the first i trailer, β_i is the angle between the moving direction of the first i trailer and the x-axis, d_i is the length of the connecting shaft for the first i-1 trailer and the first i trailer. Assuming the coordinate of the centroid in the image plane is (x_m, y_m), the monocular camera model is shown below.

$$\begin{bmatrix} \dot{x}_m \\ \dot{y}_m \end{bmatrix} = \begin{bmatrix} \alpha_1 & 0 \\ 0 & \alpha_2 \end{bmatrix} \begin{bmatrix} \cos\theta_0 & \sin\theta_0 \\ -\sin\theta_0 & \cos\theta_0 \end{bmatrix} \left[\begin{bmatrix} x \\ y \end{bmatrix} - \begin{bmatrix} c_x \\ c_y \end{bmatrix} \right] + \begin{bmatrix} O_{c1} \\ O_{c2} \end{bmatrix} \tag{2}$$

where α_1 and α_2 are the two positive unknown parameters of the camera, they depend on camera depth information, focal length, and pixel magnification along both the u-axis and the v-axis, and θ_0 represent the angle along the counterclockwise direction of the u-axis and the x-axis.

Let's make $\beta_{n+1} = 0$, and define

$$
\begin{cases}
\bar{\beta}_i = [\beta_i, \ldots \beta_n]^T, \\
p_i(\bar{\beta}_i) = \prod_{j=i}^{n} \cos(\beta_j - \beta_{j+1}), \\
\tau_i(\bar{\beta}_{i-1}) = \dfrac{\partial x_{i+1}}{\partial \bar{\beta}_i} \bar{f}_i(\bar{\beta}_{i-1}), \\
c_i(\bar{\beta}_{i-1}) = p_{i-1}^2(\bar{\beta}_{i-1}) \prod_{j=i}^{n} d_j p_i(\bar{\beta}_j), \\
f_i(\bar{\beta}_{i-1}) = \dfrac{1}{d_i} \dfrac{\tan(\beta_{i-1} - \beta_i)}{p_i(\bar{\beta}_i)}, \\
f_i(\bar{\beta}_{i-1}) = [f_i(\bar{\beta}_{i-1}), \ldots, f_n(\bar{\beta}_{n-1})]^T,
\end{cases}
\tag{3}
$$

Which $i \in \{0, \ldots, n\}$. Let’s use the following coordinates and input transformations.

$$
\begin{cases}
x_0 = x_m, \\
x_1 = y_m, \\
x_2 = \tan \beta_n, \\
x_3 = \dfrac{\tan(\beta_{n-1} - \beta_n)}{d_n \cos^3 \beta_n}, \\
x_4 = \dfrac{\tan(\beta_{n-2} - \beta_{n-1})}{c_n(\bar{\beta}_{n-1})} \tau_n(\bar{\beta}_{n-1}), \\
\vdots \\
x_{n+2} = \dfrac{\tan(\beta_0 - \beta_1)}{c_2(\bar{\beta}_1)} + \tau_2(\bar{\beta}_1), \\
u_0 = p_0(\beta_0) v_0, \\
u_1 = \dfrac{1}{\cos^2(\beta_0 - \beta_1) c_2(\bar{\beta}_1)} \omega + \tau_1(\bar{\beta}_0) p_0(\bar{\beta}_0) v_0.
\end{cases}
\tag{4}
$$

We get the uncertainty chain model.

$$
\begin{cases}
\dot{x}_0 = (\alpha_1 \cos\theta_0) u_0 + (\alpha_1 \sin\theta_0) x_2 u_0, \\
\dot{x}_1 = (\alpha_2 \cos\theta_0) x_2 u_0 - (\alpha_2 \sin\theta_0) u_0, \\
\dot{x}_2 = x_3 u_0, \\
\vdots \\
\dot{x}_{n+1} = x_{n+2} u_0, \\
\dot{x}_{n+2} = u_1.
\end{cases}
\tag{5}
$$

In Model (5), the second term on the right of the first equation depends on x_2, it does not satisfy the triangular inequality condition, so model (5) is a new uncertain chain model [9].

The parameters for the model are based on the following assumptions,

(1) α_1 and α_2 are equal and unknown, θ_0 is known.

(2) α_1 and α_2 are not equal and unknown, θ_0 is known.

(3) α_1 and α_2 are equal and unknown, θ_0 is unknown.

(4) α_1 and α_2 are not equal and unknown, θ_0 is unknown.

This paper mainly discusses the first case, other cases will be studied in the future.

3. TRAJECTORY TRACKING CONTROL BASED ON ADAPTIVE SLIDING MODEL

In this section, the kinematics tracking error model with unknown parameters is obtained by combining the uncertain chain model of trailer system with its corresponding expected model. The switching controller is designed by using equivalent sliding mode control, which makes the system state error close to zero.

3.1. System error model

From the previous section we can get the uncertain chain model of the trailer system. Since the trailer system can be transformed into $\theta_0 = 0$ when θ_0 is known, there is only one unknown parameter in the system. Let's make $\alpha_1 = \alpha_2 = \alpha$ and $\theta_0 = 0$, then the formula (5) can be written as a chain model with one unknown parameter. As follows.

$$\begin{cases} \dot{x}_0 = \alpha u_0 \\ \dot{x}_1 = \alpha x_2 u_0 \\ \dot{x}_2 = x_3 u_0 \\ \vdots \\ \dot{x}_{n+1} = x_{n+2} u_0 \\ \dot{x}_{n+2} = u_1 \end{cases} \tag{6}$$

The expected reference model is

$$\begin{cases} \dot{x}_{0r} = \alpha u_{0r} \\ \dot{x}_{1r} = \alpha x_{2r} u_{0r} \\ \dot{x}_{2r} = x_{3r} u_{0r} \\ \vdots \\ \dot{x}_{n+1r} = x_{n+2r} u_{0r} \\ \dot{x}_{n+2r} = u_{1r} \end{cases} \tag{7}$$

Where x_{ir}, u_{0r}, u_{1r} represent the desired state position and expected input, respectively. Defines the tracking errors $e_i = x_i - x_{ir}$, then $\dot{e}_i = \dot{x}_i - \dot{x}_{ir}$ $(i = 0,1\ldots n+2)$.

The kinematics tracking error system model can be obtained from formula (6) and formula (7).

$$\begin{cases} \dot{e}_0 = \alpha(u_0 - u_{0r}) \\ \dot{e}_1 = \alpha[x_2(u_0 - u_{0r}) + e_2 u_{0r}] \\ \dot{e}_2 = x_3(u_0 - u_{0r}) + e_3 u_{0r} \\ \vdots \\ \dot{e}_i = x_{i+1}(u_0 - u_{0r}) + e_{i+1} u_{0r} \\ \vdots \\ \dot{e}_{n+1} = x_{n+2}(u_0 - u_{0r}) + e_{n+2} u_{0r} \\ \dot{e}_{n+2} = u_1 - u_{1r} \end{cases} \tag{8}$$

Now, by designing switching controller u_0 and u_1, it can make the tracking error

$$e_i = x_i - x_{ir} \to 0 (i = 0,1\ldots n+2).$$

3.2. Design of adaptive equivalent sliding mode controller

The basic principle of sliding mode variable structure control is that the control characteristic can force the system to move up and down with a small amplitude and high frequency along the specified state trajectory under certain characteristics. The sliding mode, that is, the sliding mode surface, can be designed, and it is independent of the

parameters and disturbances of the system. Two sliding mode functions are designed to reflect the existence of sliding mode of the system because the error system in this paper contains two control inputs u_0 and u_1.
Design two sliding mode surfaces.

$$s_1(e) = C_1^T e = \sum_{i=1}^{n+2} c_i e_i + e_0 \tag{9}$$

$$s_2(e) = C_2^T e = \sum_{i=1}^{n+1} c_i e_i + e_0 \tag{10}$$

Where e is the error vector, $C_1 = [\ 1\ c_1 \cdots c_{n+2}\ ]^T$, $C_2 = [\ 1\ c_1 \cdots c_{n+1}\ ]^T$, and $s_1 \supset s_2$, so. In sliding mode control, parameter $c_1, c_2 \cdots, c_{n+1}, c_{n+2}$ should satisfy polynomial $p^{n+2} + c_{n+2} p^{n+1} + \cdots + c_2 p + c_1$ is $Hurwitz$, where p is $Laplace$ operator [10].
Derivative for s_1 and s_2 are

$$\dot{s}_1 = \dot{e}_0 + \sum_{i=1}^{n+2} c_i \dot{e}_i = M_1 u_0 - M_2 u_{0r} + c_{n+2}(u_1 - u_{1r}) \tag{11}$$

$$\dot{s}_2 = \dot{e}_0 + \sum_{i=1}^{n+1} c_i \dot{e}_i = M_1 u_0 - M_2 u_{0r} \tag{12}$$

Where

$$M_1 = \alpha + c_1 \alpha x_2 + c_2 x_3 + \cdots + c_{n+1} x_{n+2},$$

$$M_2 = \alpha + c_1 \alpha x_2 - c_1 e_2 + c_2 x_3 - c_2 e_3 + \cdots + c_{n+1} x_{n+2} - c_{n+1} e_{n+2}$$

For the sliding mode variable structure control system, the control function is composed of two parts. One part is the approaching control u_{sw} of the system entering the sliding surface during the approaching stage, and the other is the equivalent control u_{eq} of the ideal sliding mode control when the motion of the controlled object moves near the sliding surface or along the sliding surface. Regardless of interference and uncertainty, let's make $\dot{s} = 0$, The equivalent term of sliding mode control law u_{eq} can be obtained easily, then make $u = u_{eq} + u_{sw}$, By analyzing $\dot{s}$ and substituting u to make $s\dot{s} \le -\varepsilon |s|$ found, the switching robust term u_{sw} of sliding mode control law can be obtained.
Let the equation (11) and (12) be equal to zero to get the corresponding equivalent control quantity.

$$u_{0eq} = \frac{M_2}{M_1} u_{0r}, \qquad u_{1eq} = u_{1r} + \frac{M_2}{c_{n+2}} u_{0r} - \frac{M_1}{c_{n+2}} u_0$$

To ensure that the sliding-mode arrival condition holds, I. e., $s_i \dot{s}_i \le -\varepsilon_i |s_i|, (\varepsilon_i > 0, i = 1,2)$, the switching control can be designed as follows.

$$u_{0sw} = -\frac{\varepsilon_2}{M_1} \operatorname{sgn}(s_2), \quad u_{1sw} = -\frac{\varepsilon_1}{c_{n+1}} \operatorname{sgn}(s_1)$$

The sliding mode control law is composed of equivalent control and switching control, so the sliding mode control law is as follows without considering external disturbance and unknown parameters.

$$u_0 = u_{0eq} + u_{0sw} = \frac{M_2}{M_1} u_{0r} - \frac{\varepsilon_2}{M_1} \operatorname{sgn}(\varepsilon_2),$$

$$u_1 = u_{1eq} + u_{1sw} = u_{1r} + \frac{M_2}{c_{n+2}} u_{0r} - \frac{M_1}{c_{n+2}} u_0 = u_{1r} + \frac{\varepsilon_2}{c_{n+2}} \operatorname{sgn}(s_2) - \frac{\varepsilon_1}{c_{n+2}} \operatorname{sgn}(s_1)$$

Assumption 1 For the positive unknown parameter α , there are known positive constants $\underline{\alpha}$ and $\overline{\alpha}$ to make $0 < \underline{\alpha} \le \alpha \le \overline{\alpha}$. And $\hat{\alpha}$ is the estimated value of α .

Lemma 1[11] **[Barbalat Lemma]** Let $x:[0,\infty)\to R$ be first order continuous derivable, there is a limit when $t\to\infty$, if $\ddot{x}$, $t\in[0,\infty)$ exists and is bounded, then $\lim\limits_{t\to\infty}\dot{x}(t)=0$.

From assumption 1, we know that the parameters in the system state error model (8) are unknown, so we cannot use the input obtained above to control, but based on Lemma 1 and the above analysis, we can obtain the following theorem.

Theorem 1 For the uncertain system error model (8), based on assumption 1 and equivalent sliding mode control theory, the following switching controller and parameter adaptive law are selected.

$$\begin{cases} u_0=\dfrac{M_2^*}{M_1^*}u_{0r}-\dfrac{\varepsilon_2}{M_1^*}\operatorname{sgn}(s_2) \\ u_1=u_{1r}+\dfrac{\varepsilon_2}{c_{n+2}}\operatorname{sgn}(s_2)-\dfrac{\varepsilon_1}{c_{n+2}}\operatorname{sgn}(s_1) \\ \dot{\hat{\alpha}}=\Lambda^{-1}\left[(s_1+s_2)(u_0+c_1x_2u_0-u_{0r}-c_1x_2u_{0r})\right] \end{cases} \tag{13}$$

Where

$$M_1^*=\hat{\alpha}+c_1\hat{\alpha}x_2+c_2x_3+\Lambda+c_{n+1}x_{n+2}$$

$$M_2^*=\hat{\alpha}+c_1\hat{\alpha}x_2-c_1e_2+c_2x_3-c_2e_3+\Lambda+c_{n+1}x_{n+2}-c_{n+1}e_{n+2}$$

The control input can ensure that the state errors of the system approache zero.

Proof. Based on the above analysis, the Lyapunov function is

$$V=\frac{1}{2}s_1^2+\frac{1}{2}s_2^2+\frac{1}{2}\Lambda\tilde{\alpha}^2 \tag{14}$$

Where $\tilde{\alpha}=\alpha-\hat{\alpha}$, Λ is the control gain.

$$\begin{aligned} \dot{V}&=s_1\dot{s}_1+s_2\dot{s}_2+\Lambda\tilde{\alpha}\dot{\tilde{\alpha}} \\ &=s_1\left[M_1u_0-M_2u_{0r}+c_{n+2}(u_1-u_{1r})\right]+s_2(M_1u_0-M_2u_{0r})-\Lambda\tilde{\alpha}\dot{\hat{\alpha}} \\ &=s_1\left[(M_1-\tilde{\alpha}-\tilde{\alpha}c_1x_2)u_0-(M_2-\tilde{\alpha}-\tilde{\alpha}c_1x_2)u_{0r}+c_{n+2}(u_1-u_{1r})\right] \\ &=s_2\left[(M_1-\tilde{\alpha}-\tilde{\alpha}c_1x_2)u_0-(M_2-\tilde{\alpha}-\tilde{\alpha}c_1x_2)u_{0r}\right] \\ &=s_1\left[M_1^*u_0-M_2^*u_{0r}+c_{n+2}(u_1-u_{1r})\right]+s_2\left(M_1^*u_0-M_2^*u_{0r}\right) \\ &=s_1(-\varepsilon_1\operatorname{sgn}s_1)+s_2(-\varepsilon_2\operatorname{sgn}s_2) \\ &=-\varepsilon_1|s_1|-\varepsilon_2|s_2| \end{aligned}$$

From Lyapunov stability criterion theorem. When s_1 and s_2 are not all zero, $\dot{V}<0$, when $s_1=s_2=0$, $\dot{V}=0$. $\dot{V}$ is negative semi-definite and asymptotically stable at the origin. From Lyapunov stability theory, we can know that s_1, s_2 and e_i are uniformly bounded. Because $\dot{V}$ is uniformly continuous, $\ddot{V}$ is bounded. From Lemma 1, we know that $\dot{V}\to 0$, so $s_1,s_2\to 0$, the system is stable, then $e_i\to 0$, so the error term is close to zero.

To sum up, according to Theorem 1, the switching controller (13) can ensure that all state errors of the system approach zero.

Note 1 The constant ε in the switching control u_{sw} indicates the velocity of the moving point approaching to the switching surface $s=0$. If the parameter ε is small, the approach speed is slow, and ε is large, the moving point will have a larger speed when it reaches the switching surface, and the jitter will be larger. The exponential approach law method can improve the dynamic quality of approaching movement, to make $\dot{s} = -\varepsilon\,\mathrm{sgn}(s) - ks$. The second exponential approach term enables the moving point to approach the sliding mode surface rapidly, and the first isokinetic term makes the approach velocity be not zero, which ensures the arrival of the moving point in a finite time. The increase of k and the decrease of ε in the exponential approach law can guarantee the fast approach and reduce the jitter at the same time.

Note 2 When the uncertainty of the model and the external disturbance is large, the switching gain ε should be increased, which will result in greater jitter. In order to eliminate the "buffeting" problem existing in the closed-loop system, the saturation function $sat(s)$ can be used to replace the symbolic function.

$$sat(s) = \begin{cases} 1 & s > \Delta \\ ks & |s| \le \Delta, k = \dfrac{1}{\Delta} \\ -1 & s < -\Delta \end{cases} \tag{15}$$

Of which, Δ is the boundary layer.

Note 3 Since the controller (13) contains denominator, the pole may occur. The following theorem is discussed for the case where the denominator is zero.

Theorem 2 For the formula (13), we can get the following controller and adaptive law when $M_1^* = 0$

$$\begin{cases} u_0 = u_{0r} \\ u_1 = u_{1r} + \dfrac{M_2^*}{c_{n+2}} u_{0r} - \dfrac{\varepsilon_1}{c_{n+2}} sign(s_1) \\ \dot{\hat{\alpha}} = \Lambda^{-1}\left[s_1\left(u_0 + c_1 x_2 u_0 - u_{0r} - c_1 x_2 u_{0r}\right)\right] \end{cases} \tag{16}$$

The control input can ensure that the state errors of the system approach zero.

Proof. The Lyapunov function is

$$V = \frac{1}{2} s_1^2 + \frac{1}{2}\Lambda \tilde{\alpha}^2 \tag{17}$$

$$\begin{aligned} \dot{V} &= s_1 \dot{s}_1 + \Lambda \tilde{\alpha}\dot{\tilde{\alpha}} \\ &= s_1\left[M_1 u_0 - M_2 u_{0r} + c_{n+2}\left(u_1 - u_{1r}\right)\right] - \Lambda \tilde{\alpha}\,\dot{\hat{\alpha}} \\ &= s_1\left[\left(M_1 - \tilde{\alpha} - \tilde{\alpha} c_1 x_2\right)u_0 - \left(M_2 - \tilde{\alpha} - \tilde{\alpha} c_1 x_2\right)u_{0r} + c_{n+2}\left(u_1 - u_{1r}\right)\right] \\ &= s_1\left[M_1^* u_0 - M_2^* u_{0r} + c_{n+2}\left(u_1 - u_{1r}\right)\right] \\ &= s_1\left(-\varepsilon_1 \,\mathrm{sgn}\, s_1\right) \\ &= -\varepsilon_1 |s_1| \end{aligned}$$

According to Lyapunov stability criterion theorem, $\dot{V}$ is negative semi-definite, and it is asymptotically stable at origin. From the above analysis, we can deduce $s_1 \to 0$, and because the sliding mode surface s_1 includes all the state errors, when $M_1^* = 0$, the control law can ensure that all state errors of the system approach zero.

4. SIMULATION

Supposing two trailers are attached to the tractor, that is, $n = 2$, the system parameter $c_1 = 6, c_2 = 1, c_3 = 12, c_4 = 1, \varepsilon_1 = 2,\ \varepsilon_2 = 1$, May as well make $\underline{\alpha} = 0$, $\overline{\alpha} = 3$, then we can take $\alpha = 0.9$.

Expected input $u_{0r} = 2$, $u_{1r} = 5$. Control gain $\Lambda = 3$. Let the desired position path be $x = t$, $y = \sin t$, then the desired trajectory path of the robot moving on the plane is $y = \sin x$.

Initial state error $[e_0, e_1, e_2, e_3, e_4]=[0.05,-0.2, -0.1,0.1,0.2]$, We perform the formula (13) and the formula (16) to get the simulation diagram as follows. Fig. 2 is the error diagram of equivalent sliding mode control, and Fig. 3 is the adaptive law for parameter α . Fig. 4 and Fig. 5 are the control inputs. Fig. 6 is the tracking trajectory.

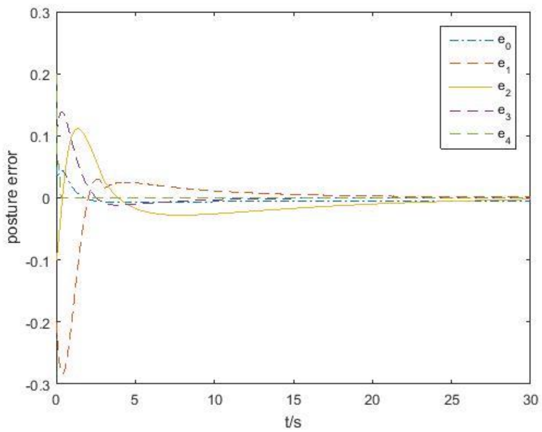


Fig. 2 The state errors for e_i （$i = 0,1,2,3,4$）

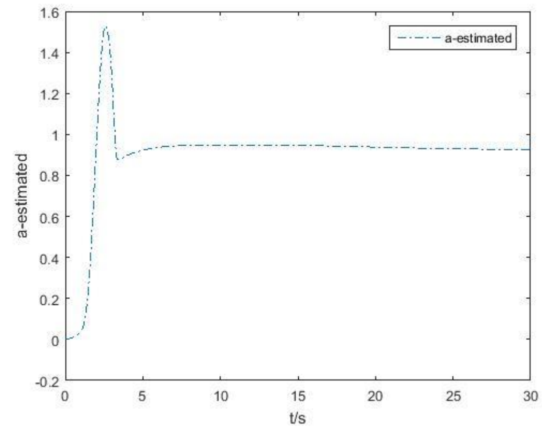


Fig. 3 Adaptive law for parameter α

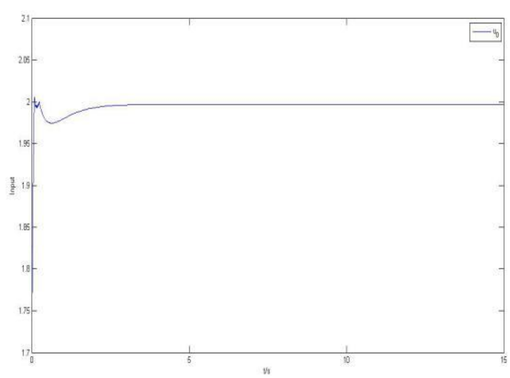


Fig. 4 Control input u_0

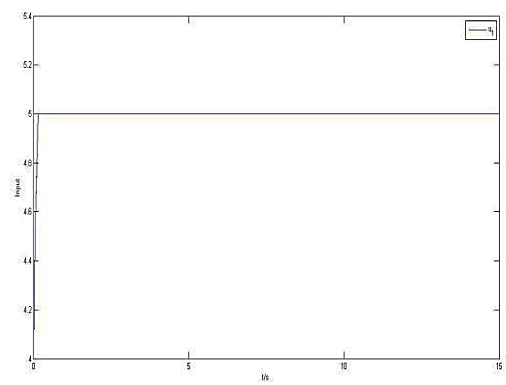
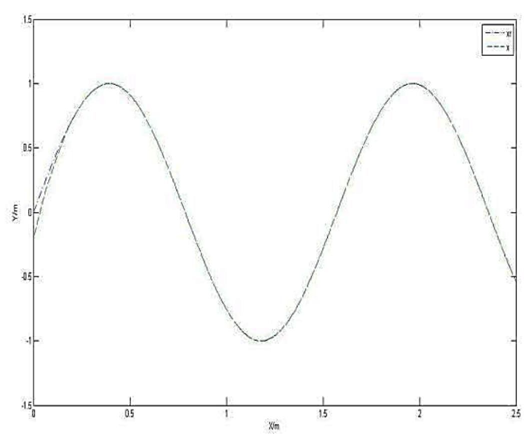


Fig. 5 Control input u_1



. *Fig. 6 Position tracking*

6. CONCLUSION

In this paper, the tracking problem of the coupling trailer under the camera is studied. The adaptive sliding mode control is used, and two sliding mode surfaces are designed for the uncertain chain system. The corresponding sliding mode variable structure controller can be obtained. It can ensure that the state errors approache zero. Then the jitter problem in sliding mode control is improved. Finally, the tracking of two trailer systems is simulated, and the simulation results show that the method is effective. In this paper, we discuss the simple case, that is, containing one unknown parameter. In the future, we will study the cases with more unknown parameter.

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