Slider Controller Design for Two-wheeled Mobile Robot Scheme

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ABSTRACT

The purpose of this paper is to effectively reduce the vibration on the continuous time of mobile control by a constant speed approaching method. Referring to mobile robot kinematics model, the system design preceded the inverted eight-mode trail tracking movement of position and speed. Angular speed was verified by actual stimulation of horizontal numeral 8 movement. The experiment proved the design can actually improve the vibration within the mechanism of two-wheeled mobile robot. It achieved stable control to the mobile robot and promoted control ability and robustness.

Keywords: constant speed approaching method, mobile control, trail tracking, robustness

兩輪移動式機器人滑動模式控制器設計

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摘　要

本文設計目的是以等速趨近方法，在連續時間上的移動式控制能有效降低抖動現象。系統設計對於移動機器人的運動學模型，將會做位置與速度的倒 8 字形軌跡跟蹤運動，角速度作曲線運動的實例模擬驗證，證實可真正改善兩輪移動式機器人的機構抖動現象，讓移動式機器人可達穩定控制，提升控制性能與強健性。

關鍵詞：等速趨近方法、移動式控制、軌跡跟蹤、強健性

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Ⅰ. INTRODUCTION

Variable structure control appeared in the 20th century which has developed over 50 years and already became a relatively independent research branch. The method can be applied to linear and nonlinear systems, continuous and discrete systems, predictability and unpredictability systems, lumped parameter and distributed parameter systems, centralized and decentralized control systems. It is gradually widely applied in actual engineering, such as electrical and power control system, robot control, flight control, etc. This control method switches the system state and moves on the surface by controlling the amount. It makes the system hold invariability while encountering parameter changes and external disturbance. This characteristic causes the attention of scholars from many countries.

Sliding model control is a simple design and an effective control method which is very sturdy toward system parameter changes and external disturbance. In MIMO systems, sliding model control can solve boundary nonlinear and coupling influence. But the chattering phenomenon is a big trouble. Although lots of literatures have been coped with chattering phenomenon[1~4], references [5,6] also proved that the system state will be limited within the range of the designer's setting and the fuzzy control system must add on a supervising controller in order to reach a complete stable requirement. In reference [7,8], the author designed a self-adjusted fuzzy sliding mode controller and adjusted the membership function which is based on an adaptive algorithm and achieved the goal of control. The induction motor is used widely at present in many industries and currently in the robot field. The characteristics are strong reliability and little maintenance [9]. The application in robots makes use of a motor's mechanical loading which must match up the specific position to make the trajectory stability control for the time changing[10]. A high-performance motor driver needs a good position tracking commend and load mediate feedback. But the induction motor will be affected by uncertainty and unpredictable mechanical equipment and the nonlinear dynamic effects of external load turbulence. The relevant calculating robot's torque control was published. If the nonlinear function of the system is smooth enough, we can assume that the estimation error range ξ is very small [11]. Variable structure control (VSC) is basically a special nonlinear control whose performance is discontinuous control[12]. This control policy differs from other control systems due to the unstable system structure. In the dynamic process, it will constantly change according to the current state of the system and make the system move by the predetermined sliding trajectory, that is, so-called "Sliding Mode Control, SMC). Since sliding mode can precede design and not relate to the object parameters and disturbance, it will make variable structure control have the advantages of quick feedback, insensitive toward parameter changes and disturbance, no need for online recognition and simple physical implementation. Therefore, this study design is based on sliding mode controller to improve the vibration of the robots and achieve the movement stability control.

II. MOBILE ROBOT KINEMATIC MODEL

As shown in Figure 1, the mobile robot is a two-wheeled mobile robot. The driving wheels are equipped with two DC motors and it has two smaller non-powered wheels which act as auxiliary wheels. The left and right wheels use rotational speed differentials of two motors to effect turning [13].

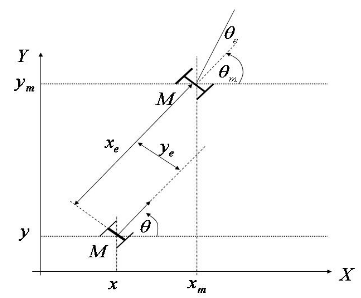

Fig.1. Mobile robot position error coordinates

The mobile robot state is presented with the position of M point on coordinates in two DC motors' driving wheels and the moving direction θ. Where, $p=(x \;\; y \;\; \theta)^T$, $q=(v \;\; w)^T$, (x,y) is the position of mobile robot, θ is the included angle of mobile moving direction and

X-axis, v and w are the input speed and input angular speed. The kinematic equation of two-wheeled robot is:

$$\dot{p}=\begin{bmatrix}\dot{x}\\ \dot{y}\\ \dot{\theta}\end{bmatrix}=\begin{bmatrix}\cos\theta & 0\\ \sin\theta & 0\\ 0 & 1\end{bmatrix}q \tag{1}$$

move position $p_m=(x_m\ y_m\ \theta_m)^T$, move speed $q_m=(v_m\ w_m)^T$. From figure1 we can get mobile robot position $p=(x\ y\ \theta)^T$ move to $p_m=(x_m\ y_m\ \theta_m)^T$, then mobile robot position error coordinates in the new coordinates X_e-Y_e,

$$p_e=(x_e,y_e,\theta_e)^T \tag{2}$$

Among $\theta_e=\theta_m-\theta_0$. Set new coordinates between X_e-Y_e and $X-Y$ included angle θ_0, according to coordinates transform function may describe mobile robot position error equation is

$$p_e=\begin{bmatrix}x_e\\ y_e\\ \theta_e\end{bmatrix}=\begin{bmatrix}\cos\theta & \sin\theta & 0\\ -\sin\theta & \cos\theta & 0\\ 0 & 0 & 1\end{bmatrix}\begin{bmatrix}x_m-x\\ y_m-y\\ \theta_m-\theta\end{bmatrix} \tag{3}$$

according to [14] get position error differential equation is

$$\dot{p}_e=\begin{bmatrix}\dot{x}_e\\ \dot{y}_e\\ \dot{\theta}_e\end{bmatrix}=\begin{bmatrix}y_e w-v+v_m\cos\theta_e\\ -x_e w+v_m\sin\theta_e\\ w_m-w\end{bmatrix} \tag{4}$$

Based on the inferential reasoning process of equation (4) and equation (1), we can obtain

$$\dot{x}=v\cos\theta,\dot{y}=v\sin\theta \tag{5}$$

then

$$\dot{x}\cos\theta+\dot{y}\sin\theta=v \tag{6}$$

$$\dot{x}\sin\theta-\dot{y}\cos\theta=0 \tag{7}$$

from equation (3), we can obtain

$$x_e=(x_m-x)\cos\theta+(y_m-y)\sin\theta$$

$$y_e=-(x_m-x)\sin\theta+(y_m-y)\cos\theta$$

$$\begin{aligned}\dot{x}_e&=(\dot{x}_m-\dot{x})\cos\theta-(x_m-x)\sin\theta\dot{\theta}+\\&\quad(\dot{y}_m-\dot{y})\sin\theta+(y_m-y)\cos\theta\dot{\theta}\\&=y_e w-(\dot{x}\cos\theta+\dot{y}\sin\theta)+(\dot{x}_m\cos\theta+\dot{y}_m\sin\theta)\\&=y_e w-v+(\dot{x}_m\cos\theta_m+\dot{y}_m\sin\theta_m)\cos\theta_e\\&\quad+(\dot{x}_m\sin\theta_m-\dot{y}_m\cos\theta_m)\sin\theta_e\\&=y_e w-v+v_m\cos\theta_e\end{aligned}$$

$$\begin{aligned}\dot{y}_e&=-(\dot{x}_m-\dot{x})\sin\theta-(x_m-x)\cos\theta\dot{\theta}+(\dot{y}_m-\dot{y})\cos\theta\\&\quad-(\dot{y}_m-\dot{y})\sin\theta\dot{\theta}\\&=-\dot{x}_m\sin\theta+\dot{y}_m\cos\theta+(\dot{x}\sin\theta-\dot{y}\cos\theta)\\&\quad-(x_m\cos\theta+y_m\sin\theta)\dot{\theta}+(x\cos\theta+y\sin\theta)\dot{\theta}\\&=-\dot{x}_m\sin\theta+\dot{y}_m\cos\theta\\&\quad-[(x_m-x)\cos\theta+(y_m-y)\sin\theta]\dot{\theta}\\&=-\dot{x}_m\sin(\theta_m-\theta_e)+\dot{y}_m\cos(\theta_m-\theta_e)-x_e w\\&=-\dot{x}_m(\sin\theta_m\cos\theta_e-\cos\theta_m\sin\theta_e)\\&\quad+\dot{y}_m(\cos\theta_m\cos\theta_e+\sin\theta_m\sin\theta_e)-x_e w\\&=[-\dot{x}_m\sin\theta_m+\dot{y}_m\cos\theta_m]\cos\theta_e\\&\quad+[\dot{x}_m\cos\theta_m+\dot{y}_m\sin\theta_m]\sin\theta_e-x_e w\\&=0+v_m\sin\theta_e-x_e w=-x_e w+v_m\sin\theta_e\end{aligned}$$

The mobile robot kinematics model's path track, seeks for the control input $q=(v\ w)^T$, causes regarding the random initial error, the system under this control input $p_e=(x_e\ y_e\ \theta_e)^T$ has the boundary

$$\lim_{t\to\infty}\left\|(x_\varepsilon\ y_\varepsilon\ \theta_\varepsilon)^T\right\|=0 \tag{8}$$

And the mobile robot kinematics model type is multi-input nonlinear system, regarding the cut function's design is a sleepy difficulty. According to [15], we can design the cut function.

III. CUT FUNCTION DESIGN

Theorem 1: for any $x\in R$ and $|x|<\infty$, when $x=0$, "=" is established.

Proof: Distinguishes the following three kind of situation discussion.

(1) when $x=0$, $\phi(0)=0$.

(2) when $x\in(0,+\infty)$, $\tan^{-1}x\in(0,\pi/2)$, then $\sin(\tan^{-1}x)>0$, namely $\phi(x)>0$.

(3) when $x\in(-\infty,0)$, $\tan^{-1}x\in(-\pi/2,0)$, then $\sin(\tan^{-1}x)<0$, namely $\phi(x)>0$.

According to the theorem 1, we can design the counter-kinematics slide model cut function. Its design process is as follows. When $x_e=0$, consider Lyapunov function

$$V_y=\frac{1}{2}y_e^2 \tag{9}$$

assume $\theta_e = -\tan^{-1}(v_m y_e)$, then

$$\dot{V}_y = y_e \dot{y}_e = y_e(-x_e w + v_m \sin\theta_e)$$
$$= -y_e x_e w + v_m y_e \sin(-\tan^{-1}(v_m y_e))$$
$$= -y_e x_e w - v_m y_e \sin(\tan^{-1}(v_m y_e)) \quad (10)$$

From theorem 1, can know

$v_m y_e \sin(-\tan^{-1}(v_m y_e)) \ge 0$, when $v_m y_e = 0$, "=" establish. Then

$$\dot{V}_y \le 0 \quad (11)$$

It can obtain the conclusion, so long as convergence zero and θ_e convergence up to $\tan^{-1}(v_m y_e)$, then the system model convergence zero. Therefore, according to this conclusion, the cut function is

$$s = \begin{bmatrix} s_1 \\ s_2 \end{bmatrix} = \begin{bmatrix} x_e \\ \theta_e + \tan^{-1}(v_m y_e) \end{bmatrix} \quad (12)$$

if $s_1 \to 0, s_2 \to 0$, and x_e convergence into zero, and θ_e convergence up to $-\tan^{-1}(v_m y_e)$, then, $y_e \to 0$ and $\theta_e \to 0$.

IV. SLIDING CONTROLLER DESIGN

In order to decrease the vibration in equation (13).

$$\dot{s} = -k \operatorname{sgn} s \quad (13)$$

we use continuous function substitutes for the sign function

$$\dot{s}_i = -k_i \frac{s_i}{|s_i| + \delta_i}, \qquad i = 1,2 \quad (14)$$

and δ_i is the decimal, set $\alpha = \tan^{-1}(v_m y_e)$, from equation (4) and equation (12), we can obtain

$$\dot{s} = \begin{bmatrix} \dot{s}_1 \\ \dot{s}_2 \end{bmatrix} = \begin{bmatrix} -k_1 \dfrac{s_1}{|s_1| + \delta_1} \\ -k_2 \dfrac{s_2}{|s_2| + \delta_2} \end{bmatrix} = \begin{bmatrix} \dot{x}_e \\ \dot{\theta}_e + \dfrac{\partial \alpha}{\partial v_m} \dot{v}_m + \dfrac{\partial \alpha}{\partial y_e} \dot{y}_e \end{bmatrix}$$

$$= \begin{bmatrix} y_e w - v + v_m \cos\theta_e \\ w_m - w + \dfrac{\partial \alpha}{\partial v_m} \dot{v}_m + \dfrac{\partial \alpha}{\partial y_e}(-x_e w + v_m \sin\theta_e) \end{bmatrix} \quad (15)$$

Rearrange equation (15), we have

$$q = \begin{bmatrix} v \\ w \end{bmatrix} = \begin{bmatrix} y_e w + v_m \cos\theta_e + k_1 \dfrac{s_1}{|s_1| + \delta_1} \\ \dfrac{w_m + \dfrac{\partial \alpha}{\partial v_m} \dot{v}_m + \dfrac{\partial \alpha}{\partial y_e}(v_m \sin\theta_e) + k_2 \dfrac{s_2}{|s_2| + \delta_2}}{1 + \dfrac{\partial \alpha}{\partial y_e} x_e} \end{bmatrix} \quad (16)$$

where $\dfrac{\partial \alpha}{\partial v_m} = \dfrac{y_e}{1 + (v_m y_e)^2}$, $\dfrac{\partial \alpha}{\partial y_e} = \dfrac{v_m}{1 + (v_m y_e)^2}$

V. SIMULATION EXPERIMENT

This paper applied sliding model controller on mobile robot and used Matlab to verify the controller's robustness and effectively simulated by a computer. The position error differential equation of the controlled object is based on equation (4), and applies carries on the simulation confirmation in the following two examples.

Case1: The simulation confirmation mobile robot's track speed and the angular speed is the uniform motion 8 character paths make the project objective inverse. Taking $w_m = 1, v_m = 1$, then $\dot{v}_m = 0$, and the radius is $\gamma = v_m / w_m$.

In move position $p_m = (x_m \ y_m \ \theta_m)^T$, $x_m = r\cos(w_m t) = \cos t$, $y_m = r\sin(w_m t) = \sin t$ and $\theta_m = w_m t = t$. And take the system parameters $\delta_1 = \delta_2 = 0.02$, $k_1 = 3.0$, $k_2 = 2.5$, the position error initial value is $[3,-3,3]$. From equation (16), the results of simulation are shown from Figure 2 to Figure 8.

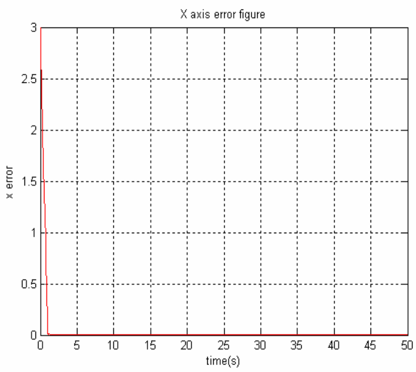

Fig. 2. X axis error chart

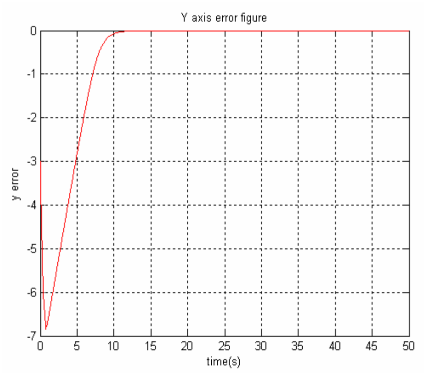

Fig.3. Y axis error chart

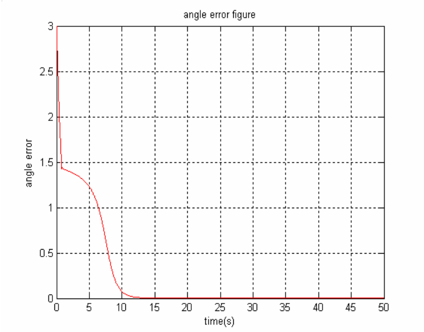

Fig. 4. Travel angle error chart

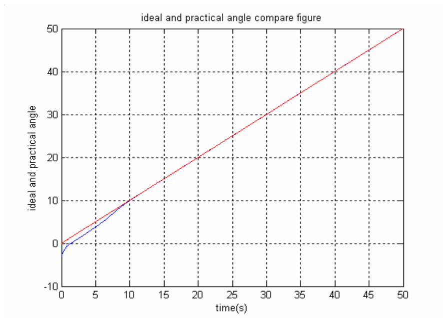

Fig. 5. Ideal and actual travel angle comparison chart

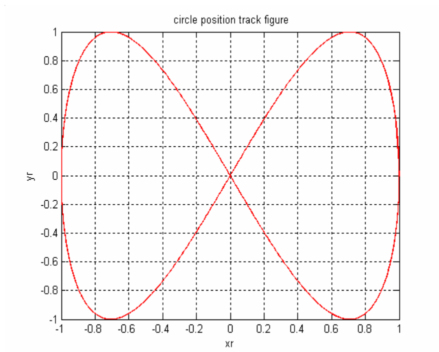

Fig. 6. Inverse 8 character position tracing chart

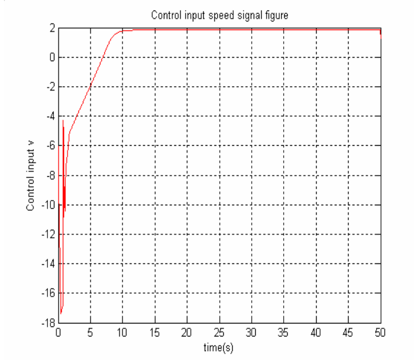

Fig. 7. Controller input speed chart

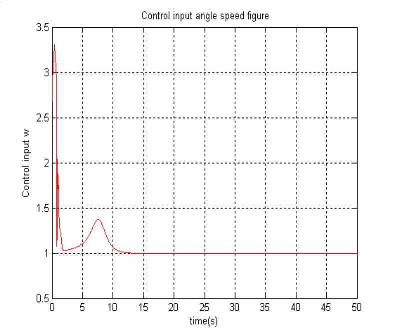

Fig. 8. Controller input angle chart

Case 2: The simulation confirmation take mobile robot's track speed as the uniform motion, the angular speed for the sinusoidal motion curve for the object design controller. Taking $w_m = \sin t, v_m = 1.0$, then $\dot{v}_m = 0$, move position $p_m = (x_m \;\; y_m \;\; \theta_m)^T$ rate of change are $\dot{x}_m = v_m \cos\theta_m$, $\dot{y}_m = v_m \sin\theta_m$ and $\dot{\theta}_m = w_m = \sin t$, then, get result in through the differential equation $p_m = (x_m \;\; y_m \;\; \theta_m)^T$. Taking $\delta_1 = \delta_2 = 0.02$, $k_1 = 3.0$,$k_2 = 2.5$, position error initial value is[1 0 0], also use control equation (16), the simulation confirmation result are shown from Figure 9 to Figure 15.

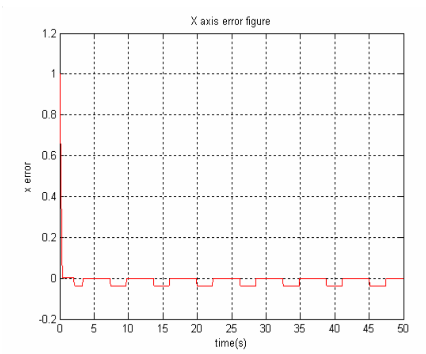

Fig. 9. X axis error chart

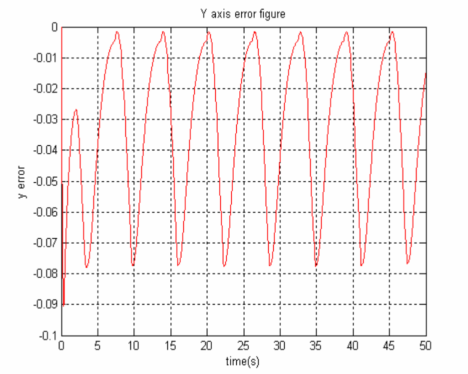

Fig. 10. Y axis error chart

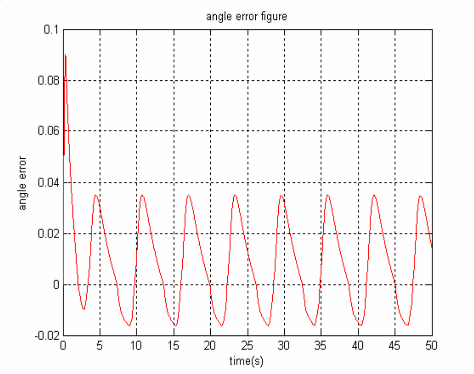

Fig. 11. Travel angle error chart

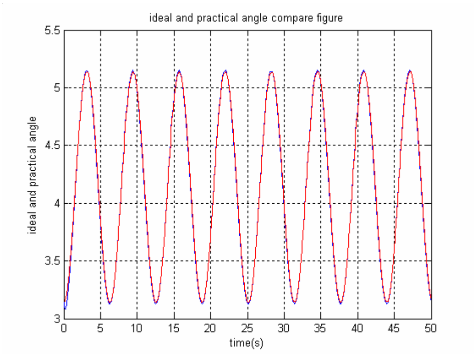

Fig. 12. Ideal and actual travel angle comparison chart

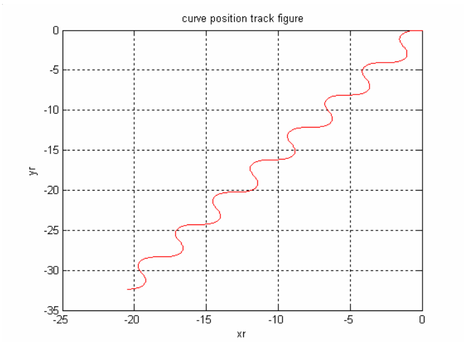

Fig. 13. Curved trajectory tracing chart

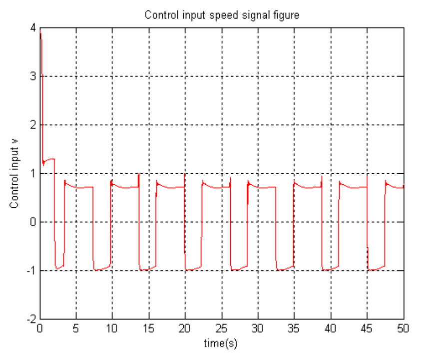

Fig. 14. Controller input speed chart

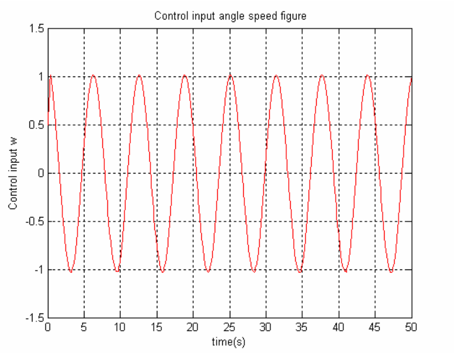

Fig. 15. Controller input angle chart

VI. CONCLUSION

The system of sliding model control can actually improve the vibration phenomenon of mobile robots. It enables two-wheeled mobile robots control to achieve stable control function within short and limit time on the tracking control of position and speed. It can also promote the efficiency of system's control respond speed. The mentioned controller of this paper can assure the trajectory tracking of the system and heading for the goal to make tracking movement. It can achieve a well control performance and robustness.

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