Control of Three-Wheeled Welding Mobile Robot

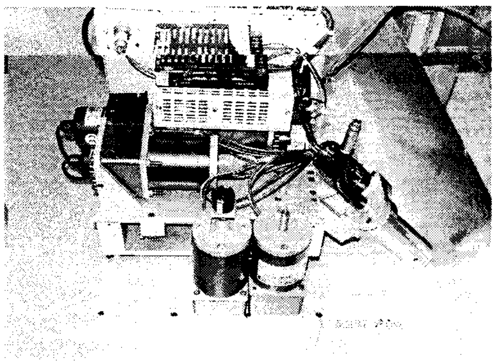
Tan Tien Nguyen*, **Tan Lam Chung****, **Myung Suck Oh**** **and Sang Bong Kim****
*Dept. of Mechanical Engineering, Hochiminh City University of Technology, Vietnam
**Dept. of Mechanical Engineering, College of Eng., Pukyong National University, Korea

Abstract: This paper proposes a simple robust nonlinear controller design method based on Lyapunov stability for tracking reference welding trajectory and velocity of a three wheel welding mobile robot (WMR). Control law is obtained from Lyapunov control function to ensure asymptotical stability of the system. The effectiveness of the proposed controller is shown through simulation results.

1. Introduction

Welding process is being strongly encouraged to improved quality, productivity and labor conditions. In the area of naval construction, automation welding process is ultimately necessary, since welding site are spatially enclosed by floors and girders, and welders are exposed to hostile working conditions. To solve this problem, some robotic welding systems have been developed recently. Santos et al.[6] developed the ROWER system, that is complex four-legged mobile platform welding machine, for application in naval construction process. There are some papers applied the two-wheeled mobile robot for welding automation. The welding mobile robot (WMR) combines of a platform of two wheeled mobile robot and a torch slider that carries the welding electrode. Jeon et al.[3,5] and Kam et al.[4] proposed a simple WMR for lattice type of welding. Jeon proposed a seam tracking and motion control of WMR for lattice type welding. There were three controllers for controlling of straight and turning locomotion and torch slider. Kam proposed a control algorithm for straight welding based on try and error each step time. The seam tracking sensor moves together with torch slider. If there is error, controller will adjust WMR motion based on pre programmed schedule. The controllers are only used for straight line tracking and cannot extent for a smooth curved line tracking. Nguyen et. al.[1,2] proposed robust controllers for two wheeled WMR in both case kinematic and dynamic model. Also a simple tactile sensor was proposed.

Our previous works[1,2] dealt with the modeling and control of two-wheeled welding mobile robot. It is successful in the laboratory experiment. However, to apply to the industrial, there is a problem needs to be solved. To carry the mobile robot body, besides two steering wheels, three are two more ball transfers. Therefore mobile robot contacts the base steel by 4 points: two wheels and two ball transfers. This is not proper case when the base steel is not completely planar and clean. A three-wheeled mobile robot platform can overcome this problem and is used in this study. This paper proposes a robust nonlinear controller design method based on Lyapunov stability for tracking reference welding trajectory and velocity of a three wheeled WMR. The system modeling and the tracking error dynamics are given to derive the controller. Control law is obtained from Lyapunov control function to ensure asymptotical stability of the system. The effectiveness of the proposed controller is shown through simulation results.



Pic. 1: Three-wheeled WMR

2. System Model

The three wheeled mobile robot using in this paper is developed by CIMEC lab, Pukyong National University. As shown in Pic.1, it includes the two driving motors, one steering motor, one z coordinate and one y coordinate carriage sliding motors. This model of mobile robot was developed as a prototype mobile robot platform to perform some tasks such as welding automation, welding slag removing, etc. When carrying a welding torch, it is called three-wheeled welding mobile robot and is studied in this paper.

We assume that the wheels roll and do not slip. The kinematic equation of WMR and relation of its coordinates with its reference welding path are shown in Fig. 1.

The ordinary form of a mobile robot with two actuated wheels can be derived as follows

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

Where $O(x,y)$ is Cartesian coordinate of middle point of two driving wheels, Φ is the heading angle of the WMR, v and ω are the linear and angular velocities of WMR at (x,y).

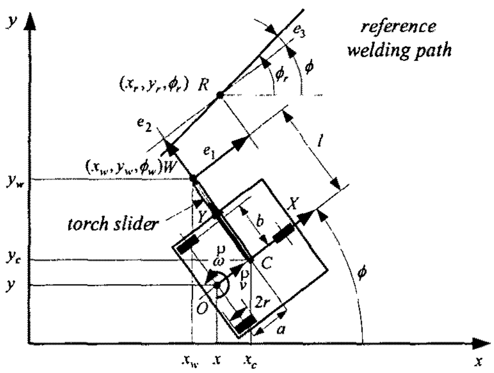


Fig. 1: Scheme for deriving WMR kinematic equations

The relationship between v and ω and the angular velocities of two driving wheels is the following

$$\begin{bmatrix} \omega_{rw} \\ \omega_{lw} \end{bmatrix} = \begin{bmatrix} 1/r & b/r \\ 1/r & -b/r \end{bmatrix} \begin{bmatrix} v \\ \omega \end{bmatrix} \quad (2)$$

where ω_{rw}, ω_{lw} represent the angular velocities of right and left wheels, b is the half distance between two driving wheels, r is driving wheel radius. The welding point coordinates $W(x_w, y_w)$ and the heading angle Φ_w can be calculated from WMR center point.

$$x_w = x_c - l\sin\phi,\ y_w = y_c - l\cos\phi,\ \Phi_w = \Phi \quad (3)$$

The geometrical relation between O and C

$$x_c = x + a\cos\Phi,\ y_c = y + a\sin\Phi \quad (4)$$

where a=OC. Hence we have

$$\begin{cases} \dot{x}_w = v\cos\Phi - a\omega\sin e\Phi - l\omega\cos\Phi - \dot{l}\sin\Phi \\ \dot{y}_w = v\sin\Phi + a\omega\cos\Phi - l\omega\sin\Phi + \dot{l}\cos\Phi \\ \dot{\Phi}_w = \omega \end{cases} \quad (5)$$

A point $R(x_r, y_r)$ moving with the constant velocity of v_r in the reference path has the coordinates and the heading angle Φ_r satisfies the following equation

$$\dot{x}_r = v_r\cos\Phi_r,\ \dot{y}_r = v_r\sin\Phi_r,\ \dot{\Phi}_r = \omega_r \quad (6)$$

where Φ_r is defined as the angle between $\overrightarrow{v_r}$ and x coordinate and ω_r is the rate of change of $\overrightarrow{v_r}$ direction.

3. Controller Design

Our objective is to design a controller for the welding point W to track the reference point R. We define the tracking errors $e = [e_1, e_2, e_3]^T$ as shown in Fig. 2

$$\begin{bmatrix} e_1 \\ e_2 \\ e_3 \end{bmatrix} = \begin{bmatrix} \cos\Phi & \sin\Phi & 0 \\ -\sin\Phi & \cos\Phi & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x_r - x_w \\ y_r - y_w \\ \Phi_r - \Phi_w \end{bmatrix} \quad (7)$$

We will design a controller to achieve $e_i \to 0$ when $t \to \infty$ and hence the welding point W tracks to its reference point R. We will consider two cases of using and no using torch slider Eq. (6) is rewritten as the following

$$\begin{bmatrix} \dot{e}_1 \\ \dot{e}_2 \\ \dot{e}_3 \end{bmatrix} = \begin{bmatrix} v_r\cos\Phi \\ v_r\sin e_3 - \dot{l} \\ \omega_r \end{bmatrix} + \begin{bmatrix} -1 & e_2 + l \\ 0 & -e_1 - a \\ 0 & -1 \end{bmatrix} \begin{bmatrix} v \\ \omega \end{bmatrix} \quad (8)$$

Choose the Lyapunov function candidate as follows

$$V_1 = \frac{1}{2}e_1^2 + \frac{1}{2}e_2^2 + \frac{1}{2}e_3^2 \geq 0 \quad (9)$$

Its derivative is

$$\begin{aligned} \dot{V}_1 &= e_1\dot{e}_1 + e_2\dot{e}_2 + e_3\dot{e}_3 \\ &= e_1(-v + l\omega + v_r\cos e_3) + e_2(v_r\sin e_3 - \dot{l} - a\omega) \\ &\quad + e_3(-\omega + \omega_r) \end{aligned} \quad (10)$$

To achieve the negativity of $\dot{V}_1$, we choose (v, ω) as follows

$$\begin{cases} v = l(\omega_r + k_3 e_3) + v_r\cos e_3 + k_1 e_1 \\ \omega = \omega_r + k_3 e_3 \end{cases} \quad (11)$$

and torch length l satisfies

$$\dot{l} = v_r\sin e_3 + a\omega + k_2 e_2 \quad (12)$$

From Eqs. (2) and (11) or (12), we can calculate the necessary velocities of two driving wheels v_l and v_r.

Depending on the position of instantaneous center of zero velocity of mobile robot platform (Fig. 2), the steering wheel (front wheel) must be steered an angular α as follows

$$\begin{cases} \tan\alpha = \dfrac{b\omega\sqrt{3}}{v} & v_{\omega l}, v_{\omega r} \geq 0 \\ \tan\alpha = \dfrac{v\sqrt{3}}{b\omega} & v_{\omega l}, v_{\omega r} < 0 \end{cases} \quad (13)$$

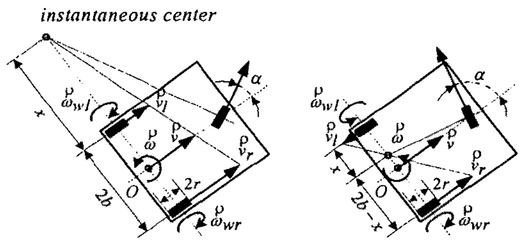


Fig. 2 The scheme for calculate the steering angular

4. Simulation Results

To verify the effectiveness of the proposed modeling and controller, simulations have been done for a WMR with a defined reference-welding path. The numerical values using in this simulation are given as Table 1. The welding speed is 7.5 *mm/s*.

Simulation results are given in Figs. 3-6. From the simulation results we can conclude as follows:

-The tracking errors converge to zeros in short time as shown in Fig. 3. We can adjust the controller gain k_i to get the desired performance. In application to welding process, the error e_1 is very important, hence, it must converge to zeros as fast as possible while keeping control inputs (Fig. 5) variation in an acceptable range.

- The control input such as mobile wheel velocities are smooth with small variations.
- The steering angular for the front wheel is smooth.

Therefore the proposed controller for tracking control of three-wheeled WMR can be applied

Table 1 The numerical values for simulation

Para.s	Values	Units	Para.s	Values	Units
a	0.089	m	$\Phi_r(0)$	30	deg
b	0.105	*m*	$x_w(0)$	0.110	*m*
r	0.025	*m*	$y_w(0)$	0.390	*m*
l(0)	0.240	*m*	$\Phi_w(0)$	*45*	*deg*
$v_r(0)$	0	*mm/s*	k_1	1.6	
$x_r(0)$	0.110	*m*	k_2	*0.8*	
$y_r(0)$	0.410	*m*	k_3	0.34	

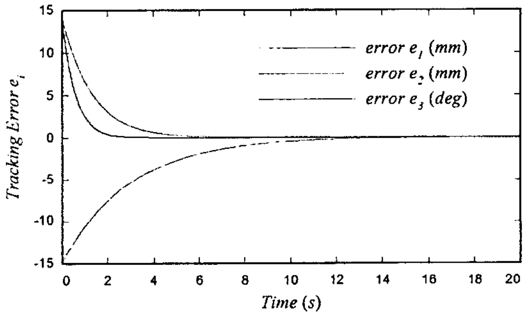


Fig. 3 Tracking errors

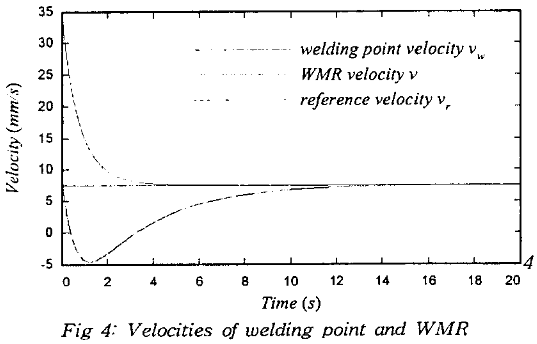


Fig 4: Velocities of welding point and WMR

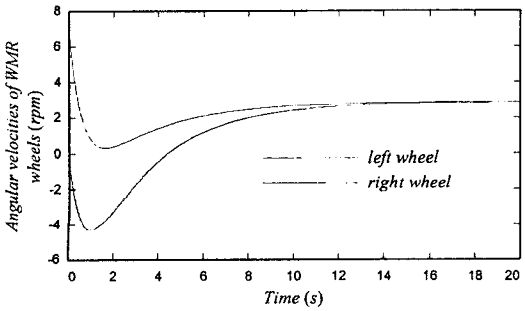


Fig 5: Control input: angular velocities of WMR wheels

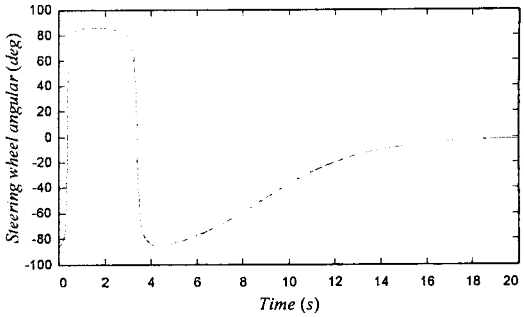


Fig. 6 Steering angular α

6. Conclusion

A three wheeled WMR system is introduce to overcome the defectiveness of a two wheeled WMR. The kinematic model of a three wheeled WMR is used. To design a tracking performance, an error configuration is defined and the controller is designed to drive the error to zero as fast as desired. The controlled system is stable in the sense of Lyapunov stability. The simulation results show that the controller can be used for the control of WMR with good performances.

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