완만한 곡선경로 추적용 이륜 용접이동로봇의 제어

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Control of Two-Wheeled Welding Mobile Robot For Tracking a Smooth Curved Welding Path

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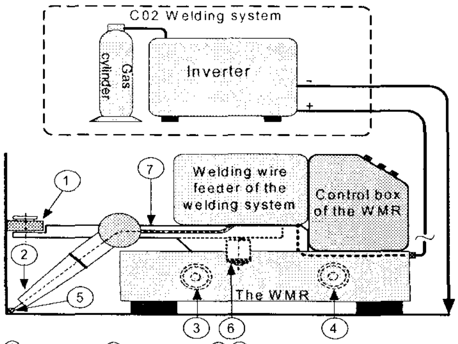
Abstract : In this paper, a nonlinear controller based on adaptive sliding-mode method which has a sliding surface vector including new boundary function is proposed and applied to a two-wheeled welding mobile robot (WMR). This controller makes the welding point of WMR achieve tracking a reference point which is moving on a smooth curved welding path with a desired constant velocity. The mobile robot is considered in view of a kinematic model and a dynamic model in Cartesian coordinates. The proposed controller can overcome uncertainties and external disturbances by adaptive sliding-mode technique. To design the controller, the tracking error vector is defined, and then the new sliding is proposed to guarantee that the error vector converges to zero asymptotically. The stability of the dynamic system will be shown through the Lyapunov method. The simulations is shown to prove the effectiveness of the proposed controller.

Key words : Welding mobile robot, Lyapunov function, nonlinear adaptive sliding-mode controller.

1. THE WMR SYSTEM

In this section, the kinematic and dynamic models of the WMR are considered with nonholonomic constraints system. The WMR is modeled under the following assumptions:

1. A torch slider is controlled by torch-slide--driving motor and located so as to coincide with the axis through the center of two driving wheels,
2. A magnet is set up at the bottom of the robot's center to avoid slipping,
3. The uncertainties and external disturbance are assumed to be unknown but slowly varying, so their derivatives are nearly to be zero.



① Touch-sensor; ② Welding torch; ③,④ left and right wheel driving motors; ⑤ welding point; ⑥ torch slider driving motor; ⑦ torch-slider

Fig. 1 Configuration of the WMR

The model of the WMR as shown in Fig. 2.

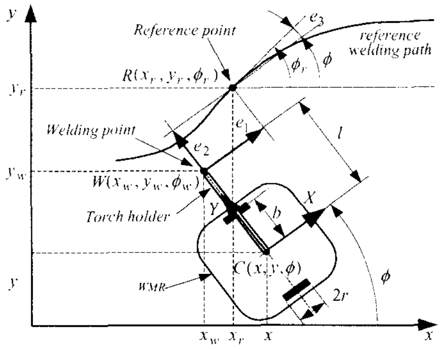


Fig. 2 WMR configuration

1.1 Kinematic Model of The WMR

The kinematic equation of the welding point $W(x_w, y_w)$ fixed on the torch holder can be derived from the WMR's center $C(x, y)$ in Fig. 2 as following:

$$\begin{cases} x_w = x - l\sin\phi \\ y_w = y + l\cos\phi \\ \phi_w = \phi \end{cases} \tag{1}$$

The derivative of (8) yields

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$$\begin{bmatrix} \dot{x}_w \\ \dot{y}_w \\ \dot{\phi}_w \end{bmatrix} = \begin{bmatrix} \cos\phi & -l\cos\phi \\ \sin\phi & -l\sin\phi \\ 0 & 1 \end{bmatrix} \begin{bmatrix} v \\ \omega \end{bmatrix} + \begin{bmatrix} -\dot{l}\sin\phi \\ \dot{l}\cos\phi \\ 0 \end{bmatrix} \quad (2)$$

where l is controlled by torch-slide-driving motor.

The coordinates (x_r, y_r) and the reference heading angle ϕ_r of the reference point R, which is moving on the reference welding path with the desired constant velocity of v_r, satisfies the following equations:

$$\begin{cases} \dot{x}_r = v_r \cos\phi_r \\ \dot{y}_r = v_r \sin\phi_r \\ \dot{\phi}_r = \omega_r \end{cases} \quad (3)$$

In Fig.2, the error vector $\mathbf{e} = [e_1, e_2, e_3]^T$ can be expressed as follows:

$$\begin{bmatrix} e_1 \\ e_2 \\ e_3 \end{bmatrix} = \begin{bmatrix} \cos\phi & \sin\phi & 0 \\ -\sin\phi & \cos\phi & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x_r - x \\ y_r - y \\ \phi_r - \phi \end{bmatrix} \quad (4)$$

1.2 Dynamic Model of The WMR

The real dynamic equation of the welding mobile robot with the external disturbances can be derived from (15) as follows:

$$\overline{\mathbf{M}}(\mathbf{q})\dot{\mathbf{z}} + \overline{\mathbf{V}}(\mathbf{q}, \dot{\mathbf{q}})\mathbf{z} + \boldsymbol{\tau}_d = \boldsymbol{\tau} \quad (5)$$

By a feedback linearization of the system, the controller vector $\mathbf{u} \in \mathbf{R}^{(n-m)\times 1}$ is defined by computed-torque method as follows (Yang and Kim, 1999)

$$\boldsymbol{\tau} = \overline{\mathbf{M}}(\mathbf{q})\dot{\mathbf{z}}_r + \overline{\mathbf{V}}(\mathbf{q}, \dot{\mathbf{q}})\mathbf{z} + \overline{\mathbf{M}}(\mathbf{q})\mathbf{u} \quad (6)$$

2. ADAPTIVE SLIDING-MODE CONTROLLER DESIGN

Our objective is to design a controller so that the welding point W tracks the reference point R at a desired constant velocity of welding v_r. So the designed controller makes the WMR achieve $\mathbf{e} \to 0$ as $t \to \infty$.

The sliding surfaces are defined as follows:

$$\mathbf{s} = \begin{bmatrix} s_1 \\ s_2 \end{bmatrix} = \begin{bmatrix} \dot{e}_1 + k_1 e_1 \\ \dot{e}_3 + k_2 e_3 + k_3 \psi(e_3) e_2 \end{bmatrix} \quad (7)$$

where a boundary function $\psi(\cdot)$ is as follows:

$$\psi(e_3) = \begin{cases} 0 \to 1 & \text{if } |e_3| \le \varepsilon \\ 1 \to 0 & \text{if } |e_3| \ge 2\varepsilon \\ \text{no change} & \text{if } \varepsilon < |e_3| < 2\varepsilon \end{cases} \quad (8)$$

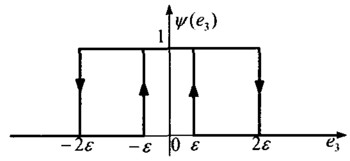

Fig. 3 Characteristic of $\psi(\cdot)$ function.

The following adaptation law and controller vector $\mathbf{u}$ are proposed to stable the sliding surface vector and make $\mathbf{e} \to 0$ as $t \to \infty$.

$$\dot{\hat{\boldsymbol{\rho}}} = \xi^{-1}\mathbf{s}(t) \quad (9)$$

$$\mathbf{u} = \begin{bmatrix} (\dot{e}_2 + \dot{l})\omega + (e_2 + l)\dot{\omega} - v_r \dot{e}_3 \sin e_3 \\ 0 \end{bmatrix} + \begin{bmatrix} k_1 \dot{e}_1 \\ k_2 \dot{e}_3 + k_3 \psi(e_3) \dot{e}_2 \end{bmatrix} + \mathbf{Qs} + |\mathbf{P}| \operatorname{sgn}(\mathbf{s}) \quad (10)$$

3. SIMULATION RESULTS:

Fig. 7 Tracking error vector with initial error vector $\mathbf{e}_{02}$

Fig. 4. shows tracking errors of the WMR. Fig.5 shows the movement of the WMR

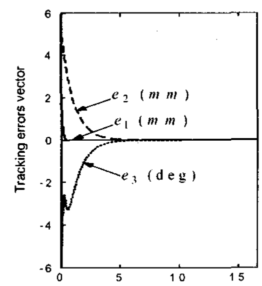

Fig. 4 Tracking error vector at the beginning

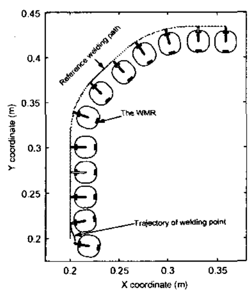

Fig. 5 Movement of the WMR along the reference welding path

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