Adaptive Tracking Controller Design for Welding Mobile Manipulator with Unknown Parameters

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ABSTRACT: This paper presents an adaptive tracking control method for a welding mobile manipulator with several unknown parameters such as the last length of the manipulator, the wheel radius and the distance from the center to the wheel. The mobile manipulator consisted of the manipulator and the mobile-platform. Kinematic modelings for the manipulator and the mobile-platform with several unknown parameters were produced. The tracking error vectors for the manipulator and the mobile-platform were defined. These adaptive controllers were designed based on the Lyapunov function to guarantee the stability of the whole system when the mobile manipulator performs a welding task. Update laws were also designed to estimate the unknown dimensional parameters. To implement the designed controllers, a control system integrated with PIC16F877 microprocessors and a TMS320C32 DSP was developed. Simulation and experimental results are presented to show the effectiveness of the proposed controllers.

1. Introduction

Nowadays, a fixed robot manipulator was used for the tasks which are harmful and dangerous for the workers. There were several literatures on a fixed robot manipulator. Lee et al. (1995) proposed a robust control scheme for real time control of the position and velocity of a fixed robot manipulator with parameter uncertainties using a multivariable feedforward controller and feedback controller. Lee (1995) proposed robust control of a fixed manipulator contacting the uncertain environment using control method. However, this fixed manipulator has a small work space. Therefore, a mobile manipulator is used for increasing the work space of the manipulator by placing the manipulator on the two-wheeled mobile-platform.

In recent years, the analysis and control of the mobile manipulator have been studied by several researchers. Yamamoto and Yun (1992) developed a control algorithm for the mobile manipulator so that the manipulator is always positioned at the preferred configurations measured by its manipulability to avoid the singularity.

Fukao et al. (2000) developed an adaptive tracking controller for the kinematic/dynamic model with the existing of unknown parameters, but the algorithm in their paper only applies for the mobile robots. Phan et al. (2005) proposed decentralized motion control of welding mobile manipulator to track along a welding trajectory with a constant velocity and a constant heading angle. Dung et al. (2007) proposed two-wheeled welding mobile robot for tracking a smooth curved welding path using adaptive sliding-mode control technique with bounding function. However, they considered a slider type of welding mobile robot. And an external disturbance was estimated by adaptive control method. All of them did not consider arc length depending on the welding conditions. Therefore, the last length of link needs to be estimated. Moreover, when a rubber wheel or a used wheel is used, wheel radius can not be known exactly. The distance from the center point to the wheel is unknown because the distance is varied depending on material or the experimental environment of the platform. They also needs to be estimated to control the welding mobile robot exactly.

This paper proposes an adaptive control algorithm for the kinematic model of the welding mobile manipulator with some unknown parameters such as the last length of manipulator, the wheel radius and the distance from the center to the wheel based on control method proposed by Phan et al. (2005). The adaptive controllers are proposed based on Lyapunov function to guarantee the stability of the whole system when the mobile manipulator performs a welding task. The update laws are designed to estimate them. The control system integrated with PIC16F877 micro-processors and TMS320C32 DSP is developed. Finally, the simulation and experimental results are presented to show the effectiveness of the proposed method. The control algorithm and results of
Fig. 1 Wheeled mobile manipulator prototype

this paper can be useful to control robots for ocean industrial fields.

2. System Modeling

The mobile manipulator prototype is shown in Fig. 1.

2.1 Kinematic equations of the manipulator

Consider a three-linked manipulator as shown in Fig. 2. A Cartesian coordinate frame is attached at the joint 1 of the manipulator. Because this frame is fixed at the center point of mobile-platform and moves in the world frame (Frame X_Y), this frame is called the moving frame (Frame x_y).

The velocity vector of the end point of the arc with respect to the world frame from the motion equation of a rigid body in a plane is obtained as follows:

$$V_E = V_P + W_P \times Rot_1^{-1} P_E + Rot_1^{-1} V_P$$

$$1^1 V_E = J \dot{\theta}$$

$$J = \begin{bmatrix}
-L_3 S_{123} - L_2 S_{12} - L_1 S_1 & -L_3 S_{123} - L_2 S_{12} & -L_3 S_{123} \\
L_3 C_{123} + L_2 C_{12} + L_1 C_1 & L_3 C_{123} + L_2 C_{12} & L_3 C_{123}
\end{bmatrix}$$

where

$$V_E = \dot{P}_E = \left[ \dot{X}_E \; \dot{Y}_E \; \dot{\phi}_E \right]^T, \quad V_P = \dot{P}_P = \left[ x_P \; y_P \; \dot{\phi}_P \right]^T,$$

$$W_P = \begin{bmatrix} 0 \; 0 \; \dot{\phi}_P \end{bmatrix}^T, \quad \dot{P}_E = \left[ x_E \; y_E \; \dot{\phi}_E \right],$$

$$0^0 \text{Rot}_1 = \begin{bmatrix} \cos \phi_P & -\sin \phi_P & 0 \\
\sin \phi_P & \cos \phi_P & 0 \\
0 & 0 & 1\end{bmatrix},$$

$$\dot{\phi}_E = \dot{\theta}_1 + \dot{\theta}_2 + \dot{\theta}_3 + \dot{\phi}_P - \frac{\pi}{2} = \dot{\phi}_E + \dot{\phi}_P - \frac{\pi}{2},$$

$$\dot{\phi}_E = \dot{\theta}_1 + \dot{\theta}_2 + \dot{\theta}_3 + \dot{\phi}_P, \quad S_1 = \sin(\theta_1), \quad S_2 = \sin(\theta_1 + \theta_2),$$

$$S_{123} = \sin(\theta_1 + \theta_2 + \theta_3), \quad C_1 = \cos(\theta_1),$$

$$C_{12} = \cos(\theta_1 + \theta_2), \quad C_{123} = \cos(\theta_1 + \theta_2 + \theta_3)$$

where $V_E$ is the velocity vector of the end point of the arc with respect to the world frame, $P_E$ is the position vector of the point $E$, $V_P$ is the velocity vector of the center point $P$ of platform with respect to the world frame, $P_P$ is the position vector of the point $P$, $W_P$ is the rotational velocity vector of the moving frame, $0^0 \text{Rot}_1$ is the rotation transform matrix from the moving frame to the world frame, $1^1 P_E$ is the position vector of the end point of the arc with respect to the moving frame, $1^1 V_E = \left[ x_E \; y_E \; \dot{\phi}_E \right]^T$ is the velocity vector of the end point of the arc with respect to the moving frame, $\dot{\theta} = [\dot{\theta}_1 \; \dot{\theta}_2 \; \dot{\theta}_3]^T$ is the angular velocity vector of the joints of the manipulator, and $J$ is the Jacobian matrix, $L_1$, $L_2$ are the length of the links and $L_3$ is the total length including the last link, torch length and arc length in the horizontal direction of the last link.

2.2 Kinematic equations of the mobile platform

When the mobile-platform moves in a horizontal plane, it obtains the linear velocity $v_P$ and the angular velocity $\omega_P$. The relation between $v_P$, $\omega_P$ and the angular velocities of two driving wheels is given by

$$\begin{bmatrix} \omega_{w_r} \\ \omega_{w_l} \end{bmatrix} = \begin{bmatrix} 1/r & b/r \\ 1/r & -b/r \end{bmatrix} \begin{bmatrix} \omega_{l} \\ \omega_{r} \end{bmatrix}$$

where $\omega_{w_r}$, $\omega_{w_l}$ are the angular velocities of the right and left wheels, $r$, $b$ are the wheel radius and the distance from the center point $P$ to the wheel, respectively.
where reference velocity vector and diag by Phan et al. (2005) as follows:

The chosen Lyapunov function is defined as

\[ V_0 = \frac{1}{2} x^T E E x \]  \hspace{1cm} (5)

\[ \dot{V}_0 \leq 0 \] is established if the time derivative of the Laypunov function is given as follows:

\[ E_x = AA^{-1} E_x + A[V_R - (V_p + W_p \times \dot{\psi}_r)^T P_E + \dot{\Psi}_R J_{\dot{\psi}}] \]  \hspace{1cm} (6)

where \( E_x = [e_1, e_2, e_3]^T \) is the tracking error vector, \( K = \text{diag}(k_v, k_s, k_h) \) with positive values \( k_v, k_s \) and \( k_h \), \( V_R \) is the reference velocity vector and \( P_R \) is the reference vector.

The non-adaptive control law of the manipulator is given by Phan et al. (2005) as follows:

\[ \dot{\theta} = J^{-1} \dot{\psi}_r [A^{-1} A + K' E_x] + V_R - V_p - W_p \times \dot{\psi}_r] \]  \hspace{1cm} (7)

Eq. (7) is the controller of the manipulator, and it can be re-expressed as follows:

\[ \dot{\theta} = \frac{1}{L_s} v_e S_{23} + v_e S_{23} + (v_e + v_e \omega_2) C_{i_2} + (v_e + v_e \omega_2) \]  \hspace{1cm} (8)

where \( S_{23} = \sin(\theta_2, \theta_3, \theta_4) \) and \( S_{23} = \sin(\theta_3, \theta_4) \).

3. Controllers Design

3.1 Controller design for manipulator

It is assumed that the dimensional parameters of \( L_1, L_2 \) and \( L_3 \) are known exactly. The coordinate of the mobile manipulator with the reference welding trajectory is shown in Fig. 3. Our objective is to design a controller so that the end point of the arc with the coordinates \( E(x, y, z) \) tracks to the reference point \( R(x_o, y_o, z_o) \).

The estimated matrix of \( J \) is the desired value of \( \dot{\theta}_d \) and \( \dot{\theta}_d \) is the estimated matrix of \( J \). Substituting Eq. (11) into Eq. (10) yields

\[ \dot{\theta} = J^{-1} \dot{\psi}_r - \dot{\theta}_d \]  \hspace{1cm} (11)

where \( \dot{\theta}_d = [\dot{\theta}_1, \dot{\theta}_2, \dot{\theta}_3]^T \) with \( \dot{\theta}_d \) is the desired value of \( \dot{\theta}_r \), and \( \dot{\theta}_d \) is the estimated error matrix of \( J \).

\[ \dot{\theta}_d = J^{-1} \dot{\psi}_r - \dot{\theta}_d \]  \hspace{1cm} (12)

Substituting Eq. (11) into Eq. (10) yields

\[ \dot{\theta} = [\dot{\theta}_d - \dot{\theta}_d] \dot{\theta}_d \]  \hspace{1cm} (13)

If \( \dot{\theta}_d \) is estimated, the estimated position vector of the end point of the arc becomes

\[ \dot{\theta}_d = \dot{\theta}_d + \dot{\theta}_d \]  \hspace{1cm} (14)

\[ \dot{\theta}_d = \dot{\theta}_d + \dot{\theta}_d \]  \hspace{1cm} (15)

where \( \dot{\theta}_d \) is the estimated error matrix of \( \dot{\theta}_d \).

Now, Eq. (6) can be rewritten as

\[ E_x = AA^{-1} E_x \]  \hspace{1cm} (16)

\[ + A[V_R - (V_p + W_p \times \dot{\psi}_r)^T P_E + \dot{\Psi}_R J_{\dot{\psi}}] \]
where the parameter update rule is chosen as

$$\dot{\gamma} = -\frac{1}{2}E^T\dot{E} + \dot{E}^T(\gamma A_p^T) \gamma L$$

Substituting Eq. (13) and Eq. (14) into Eq. (16) yields

$$\dot{E}_E = AA^{-1}E_E + A[V_R - (V_P + W_P \times \tilde{\theta}_E)]$$

$$+ \tilde{\theta}_E A_p \gamma L$$

(17)

$$A W_P \times \tilde{\theta}_E A_p \gamma L$$

and

$$A \gamma L$$

can be rewritten as follows:

$$A W_P \times \tilde{\theta}_E A_p \gamma L = \gamma L$$

(18)

$$A \gamma L$$

The chosen Lyapunov function and its derivative are

$$V_i = \frac{1}{2}E^T E + \frac{1}{2} \tilde{L} \gamma \tilde{L}$$

(19)

where $\gamma$ is a positive definite matrix and

$$\dot{V}_i = E^T \dot{E} + \dot{E}^T (A_p + \gamma L) \gamma L - \tilde{L} \dot{L}$$

(20)

To achieve $\dot{V}_i < 0$, the control law is chosen as Eq. (7), and the control update rule is chosen as

$$\dot{\gamma} = -\frac{1}{2}E^T \dot{E} + \dot{E}^T (A_p + \gamma L) \gamma L$$

(21)

$$E$$

(22)

point $E$ of the arc at beginning. If $M$ and $E$ do not coincide, the errors exist. In order to keep the configuration of the manipulator away from the singularity, the mobile-platform has to move so that the point $M$ tracks the point $E$. Consequently, the initial configuration of the manipulator is maintained throughout the welding process, and the singularity does not appear.

The error vector $E_M = [e_1, e_2, e_3]^T$ is defined as

$$E_M = \left[ \begin{array}{l} e_1 \\ e_2 \\ e_3 \end{array} \right]$$

(23)

$$M$$

(24)

3.2 Controller design for mobile platform

The task of the mobile-platform is to move so as to avoid the singularity of the manipulator’s configuration. A simple algorithm is proposed for the mobile-platform to avoid the singularity by keeping its initial configuration throughout the welding process.

The initial configuration of the manipulator is chosen as

$$\theta_1 = \frac{3\pi}{4}$$

$$\theta_2 = \frac{\pi}{2}$$

$$\theta_3 = \frac{\pi}{4}$$

in Fig. 4.

Let us define a point $M(X_M, Y_M)$ that coincides to the end

$$\Phi_E$$

Fig. 4 Scheme for deriving the error equations of mobile-platform.
where \( k_a, k_b \) and \( k_c \) are positive values.

In case that a rubber wheel or a used wheel is used, \( r \) can not be known exactly. \( b \) is unknown because \( b \) is varied depending on material or the experimental environment of the platform. When \( r \) and \( b \) are unknown, An adaptive controller is designed by using the estimated values of \( r \) and \( b \).

Substituting Eq. (4) into Eq. (28) yields

\[
\dot{E}_M = \begin{bmatrix}
\dot{e}_1 & e_4 & e_5 & e_6
\end{bmatrix}^T \begin{bmatrix}
v_E \cos e_6 \\
v_E \sin e_6 \\
\omega_E
\end{bmatrix} + \begin{bmatrix}
-1 & e_4 + D & 0 & 0 & 0
\end{bmatrix} \begin{bmatrix}
\dot{r} & 0 & 0 & \dot{r} & 0
\end{bmatrix} \begin{bmatrix}
\dot{\omega}_m \\
\dot{w}_{ln}
\end{bmatrix}
\]  

Let us define \( a_1 = \frac{1}{r} \) and \( a_2 = \frac{b}{r} \). Eq. (32) becomes

\[
\dot{e}_1 = v_E \cos e_6 \\
\dot{e}_2 = v_E \sin e_6 \\
\dot{e}_3 = -1 \cdot e_5 + D \\
\dot{e}_4 = 0 \\
\dot{e}_5 = 0 \\
\dot{e}_6 = 0
\]  

Eq. (4) becomes

\[
\begin{bmatrix}
\dot{\omega}_m \\
\dot{w}_{ln}
\end{bmatrix} = \begin{bmatrix}
a_1 & a_2 \\
\frac{a_1}{a_2} - \frac{a_2}{a_1}
\end{bmatrix} \begin{bmatrix}
v_P \\
v_{Pd}
\end{bmatrix}
\]  

If \( r \) and \( b \) are unknown, Eq. (34) becomes

\[
\begin{bmatrix}
\dot{\omega}_m \\
\dot{w}_{ln}
\end{bmatrix} = \begin{bmatrix}
\frac{a_1}{a_2} & \frac{a_2}{a_1} \\
\frac{a_1}{a_2} - \frac{a_2}{a_1}
\end{bmatrix} \begin{bmatrix}
v_{Pd} \\
\omega_{Pd}
\end{bmatrix}
\]  

where \( v_{Pd} \) and \( \omega_{Pd} \) are the desired values of \( v_P \) and \( \omega_P \).

\( \hat{a}_1 = \frac{1}{\hat{r}} \) and \( \hat{a}_2 = \frac{b}{\hat{r}} \) are the estimated values of \( a_1 \) and \( a_2 \).

Substituting Eq. (35) into Eq. (33) yields

\[
\begin{bmatrix}
\dot{e}_1 \\
\dot{e}_2 \\
\dot{e}_3 \\
\dot{e}_4 \\
\dot{e}_5 \\
\dot{e}_6
\end{bmatrix} = \begin{bmatrix}
v_E \cos e_6 \\
v_E \sin e_6 \\
-1 \cdot e_5 + D \\
0 \\
0 \\
0
\end{bmatrix} + \begin{bmatrix}
-1 & e_4 + \hat{D} & 0 & 0 & 0
\end{bmatrix} \begin{bmatrix}
\hat{a}_1 & 0 & 0 & \hat{a}_2 & 0
\end{bmatrix} \begin{bmatrix}
v_{Pd} \\
\omega_{Pd}
\end{bmatrix}
\]  

\[
\dot{\hat{a}}_1 = \frac{a_1}{a_2} - \frac{a_2}{a_1}
\]

where

\[
\hat{D} = \hat{L}_s \sin \left( \frac{3\pi}{4} \right) + \hat{L}_s \sin \left( \frac{3\pi}{4} - \frac{\pi}{2} \right) + \hat{L}_s \sin \left( \frac{3\pi}{4} + \frac{\pi}{2} + \frac{\pi}{4} \right)
\]

\[
v_{Pd} = \frac{a_1}{a_2} \cdot v_P = \frac{r}{b} \cdot v_P
\]

\[
\dot{\hat{a}}_2 = a_2 - \hat{a}_2
\]

Eq. (36) can be rewritten as follows:

\[
\begin{bmatrix}
\dot{\hat{a}}_1 \\
\dot{\hat{a}}_2
\end{bmatrix} = \begin{bmatrix}
a_1 & v_{Pd} \\
a_2 & v_{Pd}
\end{bmatrix} + \begin{bmatrix}
0 & \hat{D} \\
0 & \hat{D}
\end{bmatrix} \begin{bmatrix}
\hat{a}_1 & \hat{a}_2
\end{bmatrix}
\]

The chosen Lyapunov function and its derivative are given as

\[
V_3 = \frac{1}{2} e_1^2 + \frac{1}{2} e_2^2 + \frac{1}{2} e_3^2 + \frac{1}{2} \gamma_1 \dot{a}_1 + \frac{1}{2} \gamma_2 \dot{a}_2
\]

\[
\dot{V}_3 = e_1 \dot{e}_1 + e_2 \dot{e}_2 + e_3 \dot{e}_3 + \frac{1}{\gamma_1} \dot{a}_1 \hat{a}_1 + \frac{1}{\gamma_2} \dot{a}_2 \hat{a}_2
\]

\[
\dot{V}_3 = e_1 \dot{e}_1 + e_2 \dot{e}_2 + e_3 \dot{e}_3 + \frac{1}{\gamma_1} \dot{a}_1 \hat{a}_1 + \frac{1}{\gamma_2} \dot{a}_2 \hat{a}_2
\]

where

\( \frac{\hat{D}}{a_1} \frac{\hat{D}}{a_2} \) and \( \frac{\hat{D}}{a_1} \frac{\hat{D}}{a_2} \) are the estimated values of \( a_1 \) and \( a_2 \).

![Reference welding path](image-url)

(a) Touch sensor

(b) Scheme of measuring errors of \( e_1, e_2, e_3 \)

Fig. 5 Touch sensor used in experiment
The controller is still Eq. (30) and Eq. (31), but there is two update laws as follows:
\[ \dot{a}_1 = \tau_{pf} e_z x_H \]  
\[ \dot{a}_2 = \tau_{pf} y_H \left( e_z - e_3 \right) \]

4. Measurement of the Errors

The touch sensor prototype is shown in Fig. 5(a). Fig. 5(b) shows a simple measurement scheme using potentiometers to obtain the errors as proposed by Phan et al. (2005).

From Figs. 4-5, the relation for the errors \( e_1-e_6 \) are given as
\[ e_1 = -r \sin \theta_3; \quad e_2 = d + r \cos \theta_3; \quad e_3 = \angle (O, E, O, \theta) - \frac{\pi}{2} \]
\[ e_4 = x_e - x_O = L_{pos} \theta_3 + L_{pos} (\theta_1 + \theta_3) + L_{pos} (\theta_1 + \theta_3 + \theta_2) \]
\[ e_5 = y_e - y_O = L_{pos} \theta_3 + L_{pos} (\theta_1 + \theta_3) + L_{pos} (\theta_1 + \theta_3 + \theta_2) - \frac{\pi}{2} \]
\[ e_6 = \phi_e - \frac{\pi}{2} = (\theta_1 + \theta_3 + \theta_2) - \frac{\pi}{2} \]

where \( r \) is the radius of the roller, \( d \) is the distance from the center \( O \) to the end point of torch, and the joint angles \( \theta_1, \theta_2, \theta_3 \) can be determined from the rotary potentiometers which are assembled at the joints of the manipulator.

5. Control System Development

The total configuration of the control system is developed based on DSP-PIC microcontroller for the mobile manipulator which can implement a complicated control law as shown in Fig. 6 and the control system developed in this paper in Fig. 7. The control system is modularized as function to perform special control. The control system is based on the integration of two levels of controllers: device controller and master controller. The former is based on six PIC16F877 microprocessors of which one PIC16F877 has a function as interface between the two levels, and the others are left-wheel controller, right-wheel controller, joint-1 controller, joint-2 controller and joint-3 controller to drive the wheels and the joints, respectively; the latter is based on TMS320C32 DSP processor which renders the control law and sends command to the device controller.

The device controllers are DC motor drivers that perform indirectly servo control using one encoder. The two A/D ports on master controller are connected to the two

![Diagram of control system](image_url)
potentiometers for sensing the errors, and the three others are connected to measure the angle of the link needed for the controller. The interface controller links to the servo controllers via I2C communication, and the interface controller, in turn, links to the master controller via RS232 communication. For operation, the master controller receives signals from sensors to achieve the errors, the control laws are rendered based on the errors for the sampling time of 100 ms, and the velocity commands are sent to the five servo controllers, respectively. The parameters of the system such as controller’s constants are set by display and keypad.

6. Simulation and Experimental Results

Table 1 shows the parameters and the initial values for the welding wheeled mobile manipulator system used in this simulation and experiment. Table 2 shows that the values of the parameters of the welding wheeled mobile manipulator system used in this simulation and experiment can be measured and not known exactly.

Figure 8 shows the trajectories and mobile manipulator posture. Figures 9–10 show the angle values and the angular velocities of each link joint. They keep constant values after 10 seconds. Figures 11–12 show the velocities of the mobile platform and the angular velocities of left and right wheels of the mobile platform. They keep constant values with period of about 160 seconds. Figures 13–17 show the estimated values keep constant values after 6 seconds The estimated length of each link converges to 200 mm.

Figures 18–23 show the tracking errors of the manipulator \( e_1, e_2, e_3 \) and the tracking errors of the mobile-platform \( e_4, e_5, e_6 \). They converge to zero after 10 seconds. They show that the experiment results follow the simulation results well.

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Table 1: The numerical values and initial values for simulation and experiment

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Values</th>
<th>Units</th>
<th>Parameters</th>
<th>Values</th>
<th>Units</th>
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</thead>
<tbody>
<tr>
<td>( v_R )</td>
<td>0.0075 m/s</td>
<td></td>
<td>( \theta_1 (t = 0) )</td>
<td>-90</td>
<td>deg.</td>
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<tr>
<td>( k_1 )</td>
<td>1.4</td>
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<td>( \theta_2 (t = 0) )</td>
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<td>deg.</td>
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<td>( k_2 )</td>
<td>1.5</td>
<td></td>
<td>( X_R - X_E (t = 0) )</td>
<td>0.005</td>
<td>m</td>
</tr>
<tr>
<td>( k_3 )</td>
<td>1.7</td>
<td></td>
<td>( Y_R - Y_E (t = 0) )</td>
<td>0.005</td>
<td>m</td>
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<tr>
<td>( k_4 )</td>
<td>1.6</td>
<td></td>
<td>( \Phi_R - \Phi_E (t = 0) )</td>
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<td>deg.</td>
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<tr>
<td>( k_5 )</td>
<td>0.5</td>
<td></td>
<td>( X_E (t = 0) )</td>
<td>0.275</td>
<td>m</td>
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<tr>
<td>( k_6 )</td>
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<td></td>
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<td>m</td>
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<td>( \theta_1 (t = 0) )</td>
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<td>( \gamma_1 )</td>
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<td>( \gamma_2 )</td>
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<td>( \gamma_3 )</td>
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<td>( \gamma_3 )</td>
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Table 2: The parameter values for simulation and experiment

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<th>Actual values</th>
<th>Units</th>
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<td>0.2</td>
<td>m</td>
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<tr>
<td>( r )</td>
<td>0.195</td>
<td>0.2</td>
<td>m</td>
</tr>
<tr>
<td>( L_1 )</td>
<td>0.195</td>
<td>0.2</td>
<td>m</td>
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<tr>
<td>( L_2 )</td>
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<td>0.105</td>
<td>m</td>
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<td>( L_3 )</td>
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<td>0.025</td>
<td>m</td>
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</tbody>
</table>
Fig. 9 Angle values of link joints

Fig. 10 Angular velocities of link joints

Fig. 11 Velocities of the mobile platform

Fig. 12 Angular velocities of two wheels

Fig. 13 Estimated value of $L_1$

Fig. 14 Estimated value of $L_2$

Fig. 15 Estimated value of $L_3$

Fig. 16 Estimated value of $a_1$
7. Conclusions

This paper proposed an adaptive tracking control method for the welding mobile manipulator with the unknown parameters to track along a reference trajectory with constant velocity based on its kinematic modeling. Two independent controllers are proposed to control two subsystems such as the mobile platform and the manipulator. The controllers are designed based on the Lyapunov function to guarantee the tracking stability of the welding mobile robot. The unknown parameters of the mobile manipulator are estimated by using update law in adaptive control scheme. To implement the proposed controllers, the control system is developed based on DSP-PIC microcontroller. The simulation and experiment results show that the proposed controllers will be effective in
their real application because all of the errors converges to zero after 10 seconds.

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References


