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RESEARCH ARTICLE

ADAPTIVE SLIDING MODE CONTROL OF MOBILE MANIPULATOR WELDING SYSTEM FOR FLAT HULL BLOCK

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ABSTRACT

In this paper, an adaptive sliding mode control of mobile manipulator welding system for horizontal fillet joints is presented. The requirements of welding task are that the end effector must track along a welding trajectory with a constant velocity and must be inclined to the welding trajectory with a constant angle in the whole welding process. The mobile manipulator is divided into two subsystems such as the tree linked manipulator and the wheeled mobile platform. Two controllers are designed based on the decentralized motion method. The effectiveness of the proposed control system is proven through the simulation results.

KEYWORDS

mobile platform (MP), welding mobile manipulator (WMM), manipulator, trajectory tracking, Lyapunov function

1. INTRODUCTION

In recent years, there has been a great deal of interest in mobile robots and manipulators. The study about mobile robots is mostly concentrated on a question: how to move from here to there in a structured/unstructured environment. It includes three algorithms that are the point to point, tracking and path following algorithm. The manipulator is a subject of a holonomic system. The study on manipulators is mostly concentrated on a question: how to move the end effector from here to there and it also has three algorithms like the case of the mobile robot. Although there has been a vast amount of research effort on mobile robots and manipulators in the literature, the study on the mobile manipulators is very limited. It is hopeful that this thesis will make a little contribution for the mobile manipulator research.

The previous works are concentrated on the following topics

1.1 Motion control of a wheeled mobile robot

The mobile platform is a subject of non-holonomic system. Assume that the wheels roll purely on a horizontal plane without slippage. The mobile platform robot used in this study has two independent driving wheels and one passive caster for balancing. Several researchers studied the wheeled mobile robot as a non-holonomic system. A researcher proposed a stable tracking control method for a non-holonomic mobile robot (Kanayama et al., 1991). The stability is guaranteed by Lyapunov function. Another researcher used the backstepping kinematic into dynamic method to control a non-holonomic mobile robot (Fierro and Lewis, 1995). A previous study proposed an adaptive control for a non-holonomic mobile robots using the computed torque method (Lee et al., 1999). A group of researcher developed an adaptive tracking control method with the unknown parameters for the mobile robot (Fukao et al., 2000). Another research also proposed a tracking control method with the tracking point outside the mobile robot (Bui et al., 2003).

1.2 Motion control of a manipulator

The control of a manipulator is an interesting area for research. In previous works, a researcher proposed an algorithm for estimating parameters on-line using an adaptive control law with the computed torque method for the control of manipulators (Craig et al., 1986). A study proposed a singularity control method for the manipulator using closed-form kinematic solutions (Lloyd et al., 1993). A previous scholar proposed a decentralized robust control of a robot manipulator (Tang et al., 1998).

1.3 Motion control of a mobile manipulator

A manipulator mounted on a mobile platform will get a large workspace, but it also has many challenges. With regard to the kinematic aspect, the movement of the end effector is a compound movement of several coordinate frames at the same time. With regard to the dynamic aspect, the interaction between the manipulator and the mobile platform must be considered. With regard to the control aspect, whether the mobile manipulator is considered as two subsystems is also a problem that must be studied.

In previous works, a group of researcher studied a tracking control of a mobile manipulator with the effect of the interaction between two subsystems (Dong et al., 2000). Other researcher proposed a control method for mobile manipulator using kinematic model (Tung et al., 2004).

A researcher proposed a "Two-Wheeled Welding Mobile Robot for Tracking a Smooth Curved Welding Path Using Adaptive Sliding-Mode Control Technique" (Dung et al., 2007)

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2. System Modeling

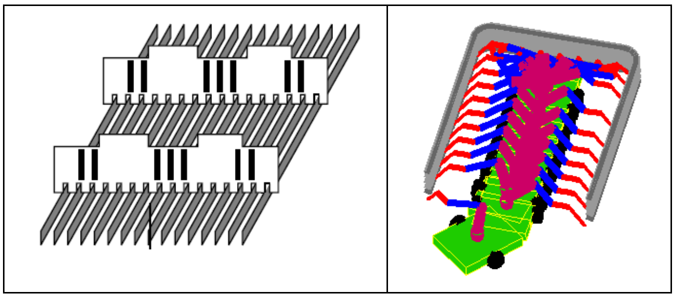

Figure 1: Assembling method for flat hull block and Three-link welding manipulator mounted on mobile platform

The task is to track the horizontal fillet seam in the grillage assembling method, which is one of the conventional procedures for assembling the flat hull blocks in shipbuilding and consists of only the horizontal fillet seam.

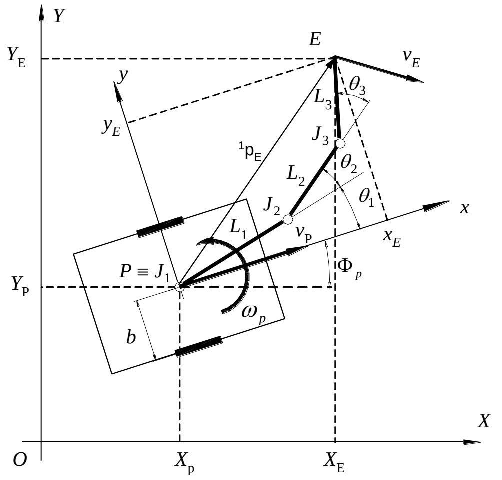

Figure 2: Schematic diagram of mobile platform-manipulator

Figure 1 The mobile manipulator is compose of a wheeled mobile platform and a manipulator. The manipulator has two independent driving wheels which are at the center of each side and two passive castor wheels which are at the center of the front anh the rear of the platform.

Figure 2 shows the schematic of the mobile manipulator considered in this paper. The following notations will be used in the derivation of the dynamic equations and kinematic equations of motion.

2.1 Kinematic equations

Consider a three-linked manipulator as shown in Figure 2. The velocity vector of the end-effector with respect to the moving frame is given by (1).

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

Where ${}^1V_E = \left[\dot{x}_E\ \dot{y}_E\ \dot{\phi}_E\right]^T$ is the velocity vector of the end-effector with respect to the moving frame, $\dot{\theta} = \left[\dot{\theta}_1\ \dot{\theta}_2\ \dot{\theta}_3\right]^T$ is the angular velocity vector of the revolution joints of the three-linked manipulator, and J is the Jacobian matrix.

$$J = \begin{bmatrix} -L_3S_{123} - L_2S_{12} - L_1S_1 & -L_3S_{123} - L_2S_{12} & -L_3S_{123} \\ L_3C_{123} + L_2C_{12} + L_1C_1 & L_3C_{123} + L_2C_{12} & L_3C_{123} \\ 1 & 1 & 1 \end{bmatrix} \tag{2}$$

where L_1, L_2, L_3 are the length of links of the manipulator, and

$$C_1 = \cos(\theta_1);\ S_1 = \sin(\theta_1);\ C_{12} = \cos(\theta_1 + \theta_2);$$
$$C_{123} = \cos(\theta_1 + \theta_2 + \theta_3);\ S_{12} = \sin(\theta_1 + \theta_2);$$
$$S_{123} = \sin(\theta_1 + \theta_2 + \theta_3);$$

The dynamic equation of the end-effector of the manipulator with respect to the world frame is obtained as follows:

$$V_E = V_P + W_P \times {}^0Rot_1\ {}^1p_E + {}^0Rot_1\ {}^1v_E \tag{3}$$

Where

$$v_E = \begin{bmatrix} \dot{X}_E \\ \dot{Y}_E \\ \dot{\Phi}_E \end{bmatrix};\quad v_P = \begin{bmatrix} \dot{X}_P \\ \dot{Y}_P \\ \dot{\Phi}_P \end{bmatrix};\quad W_P = \begin{bmatrix} 0 \\ 0 \\ \dot{\Phi}_P \end{bmatrix};\quad {}^1p_E = \begin{bmatrix} x_E \\ y_E \\ \phi_E \end{bmatrix};$$

$${}^1p_E = \begin{bmatrix} L_1C_1 + L_2C_{12} + L_3C_{123} \\ L_1S_1 + L_2S_{12} + L_3S_{123} \\ \phi_E \end{bmatrix}\quad {}^0Rot_1 = \begin{bmatrix} \cos\Phi_P & -\sin\Phi_P & 0 \\ \sin\Phi_P & \cos\Phi_P & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

$$\Phi_E = \theta_1 + \theta_2 + \theta_3 + \Phi_P - \frac{\pi}{2};\ \dot{\Phi}_E = \dot{\theta}_1 + \dot{\theta}_2 + \dot{\theta}_3 + \dot{\Phi}_P$$

The relationship between *v*, ω and the angular velocities of two driving wheels is given by

$$\begin{bmatrix} \omega_R \\ \omega_L \end{bmatrix} = \begin{bmatrix} 1/r & b/r \\ 1/r & -b/r \end{bmatrix} \begin{bmatrix} v_p \\ \omega_p \end{bmatrix} \tag{4}$$

Where *b* is the distance between the driving wheels and the axis of symmetry, *r* is the radius of each driving wheel.

The linear velocity and the angular velocity of the end-effector in the world coordinate (frame X-Y)

$$v_E = \dot{X}_E \cos\Phi_E + \dot{Y}_E \sin\Phi_E;\ \omega_E = \dot{\Phi}_E \tag{5}$$

2.2 Dynamic equations

In this application, the welding speed is very slow so that the manipulator motion during the transient time is assumed as a disturbance for MP. For this reason, the dynamic equation of the MP under nonholonomic constraints in $A(q_v)\dot{q}_v = 0$ is described by Euler-Lagrange formulation as follows:

$$M_v(q_v)\ddot{q}_v + C_v(q_v, \dot{q}_v)\dot{q}_v = E(q_v)\tau_v - A^T(q_v)\lambda \tag{6}$$

Consider a WMM as shown in Figure 2. It is model under the following assumptions:

- The MP has two driving wheels for body motion, and those are positioned on an axis passed through its geometric center.
- The three-linked manipulator is mounted on the geometric center of the MP.
- The distance between the mass center and the rotation center of the MP is *d*. Figure 2 doesn't show this distance. This value will be presented in the dynamic equation of MP.
- A magnet is set up at the bottom of the WMM to avoid slipping.

3. Controllers Design

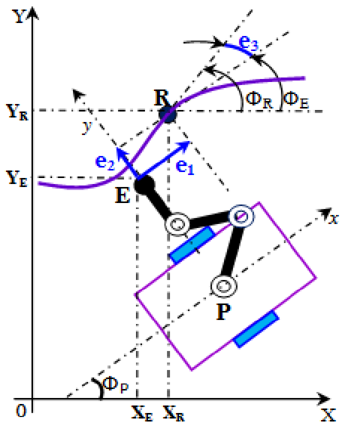

Figure 3: Scheme for deriving the tracking error vector $\mathbf{E_E}$ of manipulator

As the view point of control, this thesis addressed to an adaptive dynamic control algorithm. All of them are based on the Lyapunov function to guarantee the asymptotically stability of the system and based on the decentralized motion control method to establish the kinematic and dynamic models of system.

3.1 Defined the errors

From Figure 4, the tracking error vector $\mathbf{E_E}$ is defined as follows:

$$E_E = \begin{bmatrix} e_1 \\ e_2 \\ e_3 \end{bmatrix} = \begin{bmatrix} \cos\Phi_E & \sin\Phi_E & 0 \\ -\sin\Phi_E & \cos\Phi_E & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} X_R - X_E \\ Y_R - Y_E \\ \Phi_R - \Phi_E \end{bmatrix} \tag{7}$$

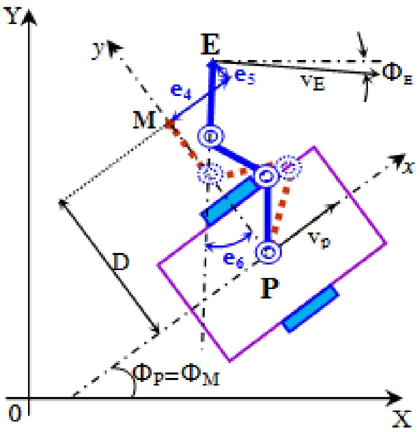

Figure 4: Scheme for deriving the MP tracking error vector

From Figure 4, A new tracking error vector $\mathbf{E_M}$ for MP is defined as follows:

$$E_M = \begin{bmatrix} e_4 \\ e_5 \\ e_6 \end{bmatrix} = \begin{bmatrix} \cos\Phi_M & \sin\Phi_M & 0 \\ -\sin\Phi_M & \cos\Phi_M & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} X_E - X_M \\ Y_E - Y_M \\ \Phi_E - \Phi_M \end{bmatrix} \tag{8}$$

3.2 Kinematic controller design for manipulator

To obtain the kinematic controller a back stepping method is used. The Lyapunove function is proposed as follows:

$$V_0 = \frac{1}{2} E_E^T E_E \tag{9}$$

The first derivative of V_0 yields

$$\dot{V}_0 = \dot{E}_E E_E^T \tag{10}$$

To achieve the negativeness of $\dot{V}_0$, the following equation must be satisfied

$$\dot{E}_E = -KE_E \tag{11}$$

where K=diag(k_1 k_2 k_3) with k_1, k_2 and k_3 are the positive constants. Substituting (1), (3) and (7) into (11) yields

$$\dot{\theta} = J^{-1}\ {}^0Rot_1^{-1}\left[A^{-1}\left(\dot{A}A^{-1} + K\right)E_E + V_R - V_P - W_P \times {}^0Rot_1^1 p_E\right] \tag{12}$$

3.3 Kinematic controller design for mobile platform

The Lyapunove function is proposed as follows:

$$V_1 = \frac{1}{2} E_M^T E_M \tag{13}$$

The first derivative of V_1 yields

$$\dot{V}_1 = \dot{E}_M E_M^T \tag{14}$$

To achieve the negativeness of $\dot{V}_0$, the following equation must be satisfied

$$v_p = v_E \cos e_6 + D\omega_P + k_4 e_4 \tag{15}$$

$$\omega_p = \omega_E + v_E \sin e_6 + k_5 e_5 + k_6 e_6$$

with k_4, k_5 and k_6 are the positive constants. (15)

3.4 Adaptive sliding mode controller design

To design a sliding mode controller, the sliding surfaces are defined as follows:

$$s = \begin{bmatrix} s_1 \\ s_2 \end{bmatrix} = \begin{bmatrix} \dot{e}_4 + k_4 e_4 \\ \dot{e}_6 + k_6 e_6 + k_5 \psi(e_6) e_5 \end{bmatrix} \tag{16}$$

where k_4 , k_5 and k_6 are positive constant values. $\psi(e_6)$ is a bounding function and is defined as follows:

$$\psi(e_6) = \begin{cases} 0 \to 1 & if\ |e_6| \le \varepsilon \\ 1 \to 0 & if\ |e_6| \ge 2\varepsilon \\ no\,change & \varepsilon < |e_6| < 2\varepsilon \end{cases} \tag{17}$$

Where ε is a positive constant value.

The following procedure will design an adaptation law $\dot{\hat{p}}$ and a control law u which stabilize and converge the sliding surface $s \to 0$ as $t \to \infty$

Firstly, the adaptation law is proposed as the following:

$$\dot{\hat{p}} = -\xi^{-1} s^T(t) \tag{18}$$

Where $\hat{p} = [\hat{p}_1 \ \ \hat{p}_2]^T$ is an estimate value of $f = [f_1 \ \ f_2]^T$; $\xi^{-1} = [\xi_1^{-1} \ \ \xi_2^{-1}]^T$ is positive definite vector which denotes as an adaptation gain and.

The estimation error is defined as follows:

$$\tilde{p} = f - \hat{p} \Rightarrow \hat{p} = f - \tilde{p} \tag{19}$$

Secondly, the control law u is chosen as follows:

To satisfy the Lyapunov's stability condition $\dot{V} \le 0$, the following proposed controller $\mathbf{u}_{mb}$ can be calculated as follows:

$$\mathbf{u}_{mb} = \begin{bmatrix} \dot{e}_5\omega_r + (e_5 + D)\dot{\omega}_r - v_E \dot{e}_6 \sin e_6 \\ \dot{e}_3 \end{bmatrix} + \begin{bmatrix} k_4 \dot{e}_4 \\ k_6 \dot{e}_6 + k_5\ \psi(e_6)\ \dot{e}_5 \end{bmatrix} + \mathbf{Q}s^T + \hat{P} \tag{20}$$

where $Q = \begin{bmatrix} q_{11} & 0 \\ 0 & q_{22} \end{bmatrix}$; $\hat{P} = \begin{bmatrix} \hat{p}_1 & 0 \\ 0 & \hat{p}_2 \end{bmatrix}$

The above control laws u and adaptation law $\dot{\hat{p}}$ with the assumption (8) make the sliding surfaces in Eq. (16) be stabilized and converge to zero as $t \to \infty$.

3.5 Hardware design

From Figure 5, the tracking errors relations are given as

$$e_1 = -r_s \sin e_3; \quad e_2 = d_e + r_s \cos e_3; \quad e_3 = \angle(O_1E, O_1O_3) - \frac{\pi}{2} \tag{21}$$

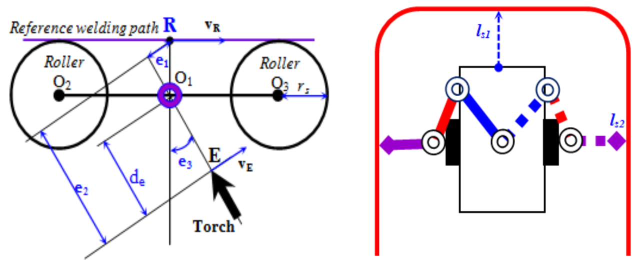

Figure 5: The scheme of measuring errors $e_{1,2,3}$ and The scheme of sensors of the mobile platform

From Figure 4, the tracking errors e_4, e_5, e_6 with respect to moving frame can be calculated as follows:

$$\begin{aligned} e_4 &= x_E - x_M = L_1 \cos\theta_1 + L_2 \cos(\theta_1+\theta_2) + L_3 \cos(\theta_1+\theta_2+\theta_3) \\ e_5 &= y_E - y_M = L_1 \sin\theta_1 + L_2 \sin(\theta_1+\theta_2) + L_3 \sin(\theta_1+\theta_2+\theta_3) - D \\ e_6 &= \phi_E - \frac{\pi}{2} = (\theta_1+\theta_2+\theta_3) - \frac{\pi}{2} \end{aligned} \tag{22}$$

3.6 Control algorithms

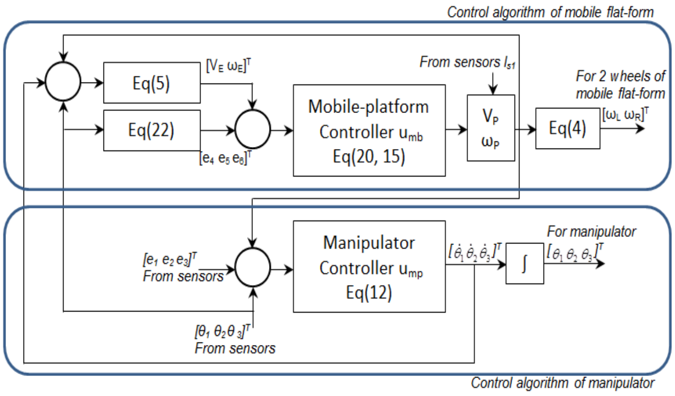

Figure 6: Block diagram of control system

The schematic diagram for a decentralized control method is shown in Figure 6. In this diagram, a relationship between controllers is illustrated by means of the output of this controller is one of the input of another controller and vice versa. The control task demands a real-time algorithm to guide the mobile manipulator in a given trajectory. Laser sensor, rotary potentiometer and linear potentiometer were adopted in the simulation to obtain the position and orientation of the mobile platform relative to the walls.

4. Simulation Results

In this section, some simulation resuls are presented to demonstrate the effectiveness o the control algorithm developed for Horizontal Fillet Joints welding.

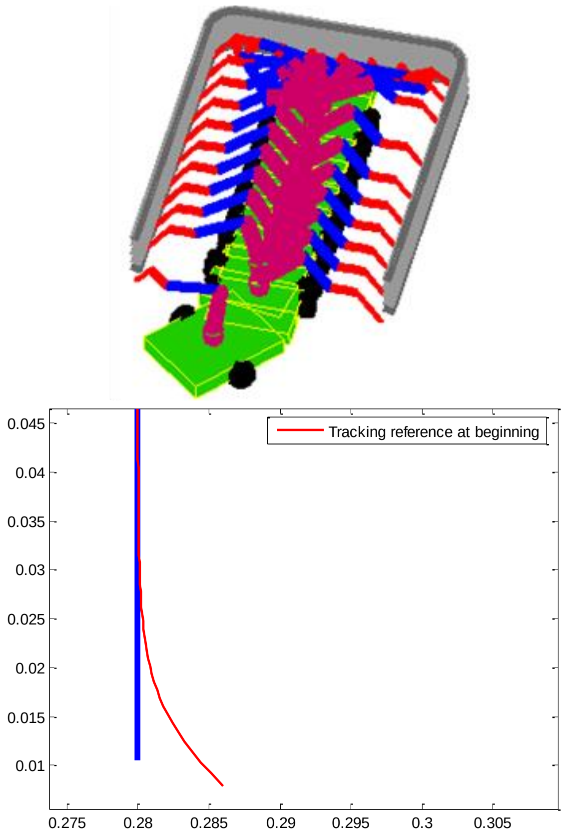

Figure 7: The WMM is tracking along the welding path and its reference at beginning

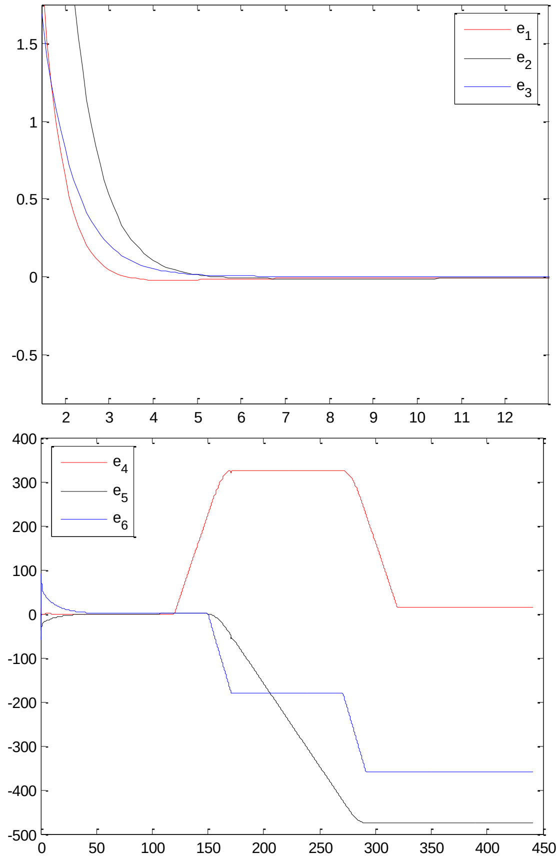

Figure 8: Tracking errors e_1 e_2 e_3 at beginning (zoom in) and Tracking errors e_4 e_5 e_6 at beginning

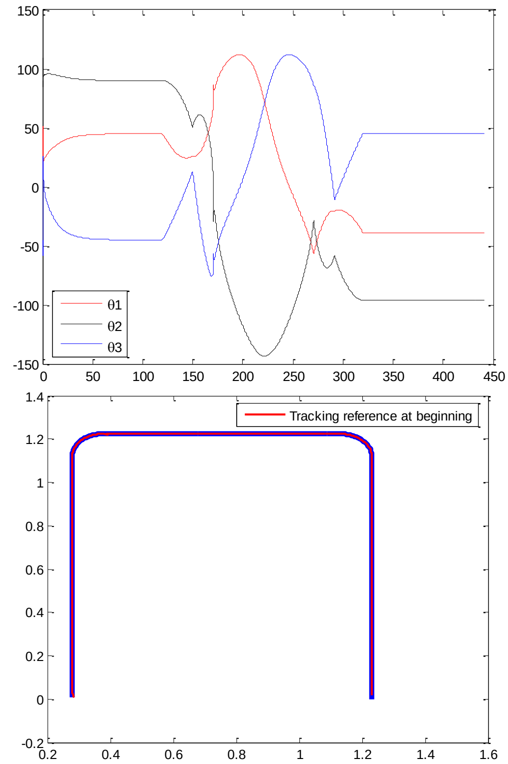

Figure 9: Angular of revolution joints and Results of trajectories of the end effector and its reference

5. Conclusion

In this study, developed a WMM which can co-work between mobile platform and manipulator for tracking a long Horizontal Fillet Joints welding path. The main task of the control system is to control the end-effector or welding point of the WMM for tracking a welding point which is moved on the welding path with constant velocity. The angle of welding torch must be kept constant with respect to the welding curve. The WMM is divided into two subsystems and is controlled by decentralized controllers. The kinematic controller and adaptive sliding mode controller are designed to control the manipulator and the mobile-platform, respectively. These controllers are obtained based on the Lyapunov's function and its stability condition to ensure the error vectors to be asymptotically stable. From the simulation results are presented to illustrate the effectiveness of the proposed algorithm.

REFERENCES

Craig, J.J., Hsu, P., Sastry, S.S. 1986. Adaptive Control of Mechanical Manipulators, Proceedings of the IEEE International Conference on Robotics and Automation, 2, pp. 190-195.

Lloyd, J., Hayward, V. 1993. Singularity Control of Robot Manipulator Using Closed Form Kinematic Solutions, Proceedings of the Conference on Electrical and Computer Engineering, 2, pp. 1065-1068.

Fierro, R., Lewis, F.L. 1995. Control of a Nonholonomic Mobile Robot: Backstepping Kinematics into Dynamics, Proceedings of the IEEE Conference on Decision and Control, 4, pp. 3805-3810.

Lee, T.C., Lee, C.H., Teng, C.C. 1999. Adaptive Tracking Control of Nonholonomic Mobile Robots by Computed Torque, Proceedings of the Conference on Decision and Control, 2, pp. 1254-1259.

Fukao, T., Nakagawa, H., Adachi, N. 2000. Adaptive Tracking Control of a Nonholonomic Mobile Robot, Transactions on Robotics and Automation, 16(5), pp. 609-615.

Bui, T.H., Chung, T.L., Suh, J.H., Kim, S.B. 2003. Adaptive Control for Tracking Trajectory of a Two Wheeled Welding Mobile Robot with Unknown Parameters, Proceedings of the International Conference on Control, Automation and Systems, pp. 191-196.

Dong, W., Xu, Y., Wang, Q. 2000. On Tracking Control of Mobile Manipulators, Proceedings of the IEEE International Conference on Robotics and Automation, 4, pp. 3455-3460.

Kanayama, Y., Kimura, Y., Miyazaki, F., Noguchi, T. 1991. A Stable Tracking Control Method for a Nonholonomic Mobile Robot, Proceedings of the IEEE/RSJ International Workshop on Intelligent Robots and Systems, Japan, 3, pp. 1236-1241.

Tang, Y., Guerrero, G. 1998. Decentralized Robust Control of Robot Manipulator, Proceedings of the American Control Conference, Pennsylvania, USA, pp. 922-926.

Tan, T.P., Thien, P.T., Trong, H.B., Sang, B.K. 2004. Decentralized Control Method for Welding Mobile Manipulator, Proceedings of the International Conference on Dynamics, Instrumentation, and Control, Nanjin, China, pp. 171-180.

Ngo, M.D., Vo, H.D., Nguyen, T.P., Sang, B.K., Myung, S.O. 2007. Two-Wheeled Welding Mobile Robot for Tracking a Smooth Curved Welding Path Using Adaptive Sliding-Mode Control Technique, Proceedings of the International Journal of Control, Automation, and Systems, 5(3), pp. 283-294.

Yoo, W.S., Kim, J.D., Na, S.J. 2001. A study on a mobile platform-manipulator welding system for horizontal fillet joints, Mechatronics, 11, pp. 853-868