Proceedings of the Korean Nuclear Society Autumn Meeting
Taejon, Korea, October 1996

Motion Control of a Mobile Robot for Nuclear Facility

Jae-Kyung Lee, Seung Ho Kim, Kiho Kim, Byung Soo Kim and Min-Suk Kim

Korea Atomic Energy Research Institute

Abstract

In order that a mobile robot executes the real tasks such as inspection and maintenance in nuclear facility efficiently, the coordination between the mobile platform and the manipulator is essentially required. In this paper, a new motion control method for a mobile robot to execute the tasks in nuclear facility efficiently is proposed. A series of simulations are performed to verify the effectiveness of the proposed method.

1. Introduction

For the execution of the real tasks in nuclear facility, the mobile robot should be equipped with a manipulator. A very important characteristic of a mobile robot equipped with a manipulator is the kinamatic redundancy introduced by the mobility of the mobile platform, which can be exploited to get broader workspace and dexterous manipulation in cluttered environments. Recently, researches on the area of coordinated motion of a mobile robot are attracting significant interest for the applications to the hazardous tasks in hostile environments, such as inspection and maintenance in nuclear power plant, radioactive waste cleanup and restoration, decommissioning obsolete nuclear facilities, and handling of toxic chemicals, etc[1]-[4]. For the coordinated motion control of mobile manipulators, several difficulties introduced by the coordination between the mobile platform and the manipulator should be resolved.

In this paper, an efficient motion control method for a mobile robot to execute the inspection and maintenance tasks in nuclear facility is proposed considering the coordination between the mobile platform and the manipulator. A series of simulations are performed to verify the effectiveness of the proposed method.

2. System Description

We are developing a mobile robot, named as KAEROT/m1, for performing hazardous tasks such as inspection/maintenance, radiological surveys and handling of radioactive materials in nuclear facilities. Figure 1 shows the KAEROT/m1.

This mobile robot has two subsystems; a mobile platform and a robotic arm. The mobile platform has four planetary wheels, which has the ability of ascending and descending stairs and navigating flat surface with zero turning radius. Each planetary wheel is equipped with three small omnidirectional wheels in an angle of 120 degrees. A three Degree-Of-Freedom omnidirectional wheel is enclosed with a circle of six rollers in shape of ellipsoid and allows the mobile platform to move in desired directions.

The robotic arm mounted on the top of the mobile platform is a six Degree-Of-Freedom joint-controlled manipulator that includes as three Degree-Of-Freedom end-effector. This manipulator is an electrically-driven type and is designed to have 5 Kg payload capacity and the ability to reach on the ground.

The mobile platform is designed to be controlled by a hand controller either through a wire or a radio command signal. The manipulator is designed to be operated by a master-slave controller. Control and sensor communication for all KAEROT/m1 parameters are managed through a VME bus with a VxWork real-time operating system.

3. Coordinated Motion Control Method

The kinematic relations for a mobile robot are given by

$$\overline{X}_e = \overline{X}_p + \overline{X}_{m/p} \tag{1}$$

where $\overline{X}_e$ is the task vector representing the end effector configuration(position and orientation) in the world frame, $\overline{X}_p$ is the mobile platform configuration (posture) vector in the world frame, and $\overline{X}_{m/p}$ is the end effector configuration vector with respect to the mobile platform reference frame.

Because the mobile platform configuration can be represented by the position of the mobile platform center point and the heading angle, $\overline{X}_p$ can be represented by

$$\overline{X}_p = \{x, y, \varphi\}^T. \tag{2}$$

Let the manipulator base frame be {B}, and $\overline{\Theta}$ be the relative manipulator joint displacement vector with respect to the manipulator base frame, then, because the relative configuration of the base frame with respect to the mobile platform frame is constant, $\overline{X}_{m/p}$ can be represented by

$$X_{m/p} = f(\varphi, \Theta) \qquad (3)$$

where $\overline{\Theta} = \{\theta_1, \theta_2, \cdots, \theta_n\}^T$.

Combining Eq.(2) and Eq.(3), then $\overline{X}_e$ can be expressed in the following form:

$$\overline{X}_e = F(\overline{q}) \qquad (4)$$

where $\overline{q} = \{x, y, \varphi, \theta_1, \theta_2, \cdots, \theta_n\}^T$.

Differentiating Eq.(4) with respect to time, we get

$$\dot{\overline{X}}_e = J(\overline{q})\dot{\overline{q}} \qquad (5)$$

where $\dot{\overline{X}}_e$ is the m-dimensional Cartesian velocity (linear and angular) vector, $J(\overline{q})$ is the $m \times (n+3)$ Jacobian matrix of the mobile manipulator and $\dot{\overline{q}}$ is the (n+3)-dimensional velocity vector.

The general solution for Eq.(5) is given by

$$\dot{\overline{q}} = J^+ \dot{\overline{X}} + (I - J^+ J)\overline{h} \qquad (6)$$

where $J^+ = J^T(JJ^T)^{-1}$ is the Moore-Penrose generalized inverse or pseudoinverse of the J, I is an $(n+3) \times (n+3)$ identity matrix, $(I - J^+ J)$ is the null space projection matrix which is orthogonal to the Jacobian matrix and the $\overline{h}$ is an arbitrary velocity vector. In the equation, the first term is the least norm solution and the second term is a homogeneous solution. The homogeneous solution corresponds to the one for instantaneous self-motion of the mobile robot because it does not affect the end effector motion. Therefore, we can get an optimal solution by selecting the homegeneous solution as to minimize or maximize a criteria function.

Introducing a scalar criteria function $H(\overline{q})$, the solution which minimizes or maximizes the criteria function is given by

$$\dot{\overline{q}} = J_{eq}^+ \dot{\overline{X}} + k(I - J_{eq}^+ J_{eq})\nabla H(\overline{q}) \qquad (7)$$

where the coefficient k is a real scalar constant, which is taken to be positive if the criteria function is to be maximized while to be negative if the criteria function is to be minimized and $\nabla H(\overline{q})$ is the gradient vector of the criteria function. A large value of k optimizes the criteria function at a faster rate, but in that case, because the actuator velocity becomes larger, the maximum allowable value of k is limited by bounds on the actuator velocities or torques.

4. Simulation

Simulations are performed for a 2-link planar mobile robot as shown in Figure 2. The desired end effector trajectory of the mobile robot is as follows:

$$\begin{aligned} x(t) &= t + 0.3813 \\ y(t) &= 0.2289 \end{aligned} \tag{8}$$

The simulation was performed for two cases; first case is the min. norm solution and the second case is the maximum manipulability measure which is given by Yoshikawa [5]

$$H(\bar{q}) = \sqrt{\det(J_{eq} J_{eq}^{T})}\ . \tag{9}$$

The kinematic equation for the mobile robot is given by

$$\begin{aligned} X_e &= x + l_1 \cos(\varphi + \theta_1) + l_2 \cos(\varphi + \theta_1 + \theta_2) \\ Y_e &= y + l_1 \sin(\varphi + \theta_1) + l_2 \sin(\varphi + \theta_1 + \theta_2) \end{aligned} \tag{10}$$

where l_1 and l_2 represent the length of each link.
Then, the Jacobian matrix is given by

$$J = \begin{bmatrix} 1 & 0 & -x s_{\varphi} - l_1 s_{\varphi 1} - l_1 s_{\varphi 12} & -l_1 s_{\varphi 1} - l_1 s_{\varphi 12} & -l_1 s_{\varphi 12} \\ 0 & 1 & y c_{\varphi} + l_1 c_{\varphi 1} + l_1 c_{\varphi 12} & l_1 c_{\varphi 1} + l_1 c_{\varphi 12} & l_1 c_{\varphi 12} \end{bmatrix}. \tag{11}$$

Figure 3 shows the desired and actual end effector trajectory. As can be seen in the figure, the end effector of the mobile robot follows the desired end effector trajectory quite accurately. This indicates that the proposed method can effectively control the mobile robot motion. Figure 4(a) and 4(b) show the motion of the mobile robot for the case of maximum manipulability measure and the minimum velocity norm, respectively. Figure 5 shows the trajectory of the mobile platform, and Figure 6 shows the variation of the manipulability measure with respect to time. In the figure, we can see that the manipulability measure for the case of maximum manipulability measure solution is higher than for the case of minimum norm solution.

5. Conclusions

In this paper, in order to make coordinated motion control of a mobile robot for nuclear facility, we proposed a new motion control method considering the motions of the mobile platform and the manipulator simultaneously. Computer simulations were performed for verification of the effectiveness of the proposed method. The simulation results show that the proposed method can be effectively used for the coordinated motion control of a mobile robot.

References

[1] Y.Yamamoto and X.Yun, "Coordinating Locomotion and Manipulation of a Mobile Manipulator," *Proc. of IEEE Int. Conf. on Decision and Control*, pp. 2643-2648, 1992.

[2] Francois G. Pin and J-C Culioli, "Optimal Positioning of Combined Mobile Platform - Manipulator Systems for Material Handling Tasks," *J. of Intelligent and Robotic Systems 6*, pp. 165-182, 1992.

[3] N.A.M. Hootsmans and S.Dubowsky, " Large motion control of mobile manipulators including vehicle suspension characteristics," *Proc. of IEEE Int. Conf. on Robotics and Automation*, pp.2336-2341,1991

[4] H.Seraji," An on-line approach to coordinated mobility and manipulation," *Proc. of IEEE Int. Conf. on Robotics and Automation*, pp.28-35,1993

[5] Yoshikawa,T., "Analysis and Control of Robot Manipulators with Redundancy," The 1st Int'l Symp., ed. Brady, M. and Paul R.P., Cambridge, Mass., MIT Press, pp. 735-748, 1984.

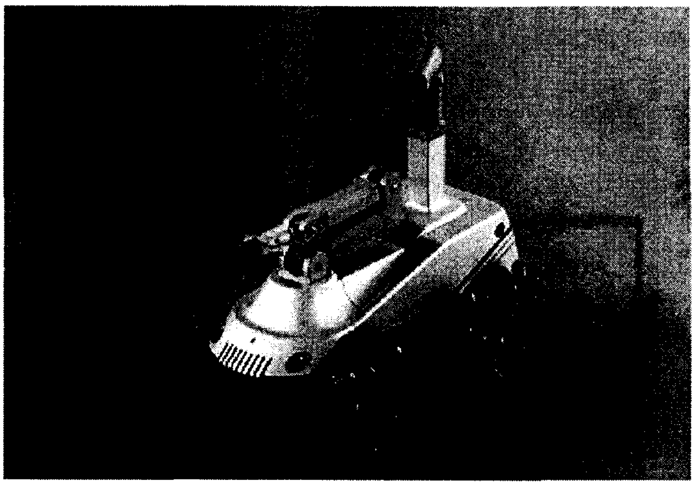


Fig. 1. *The mobile robot KAEROT/m1.*

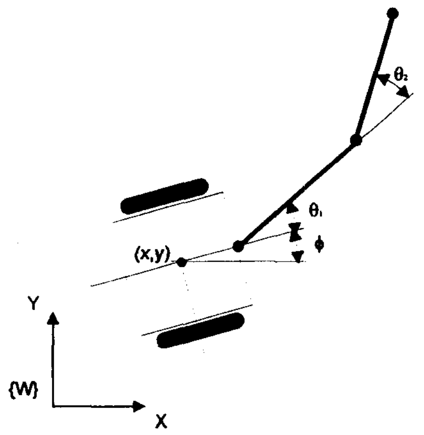


Fig. 2. *2-link planar mobile manipulator used in the simulation.*

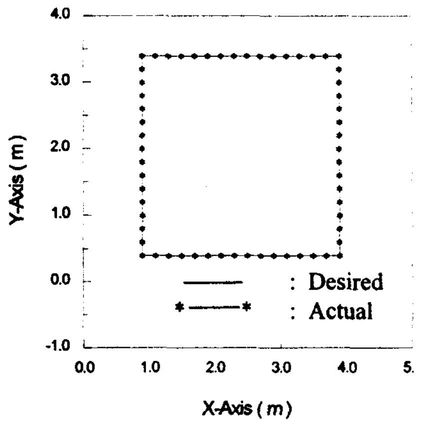
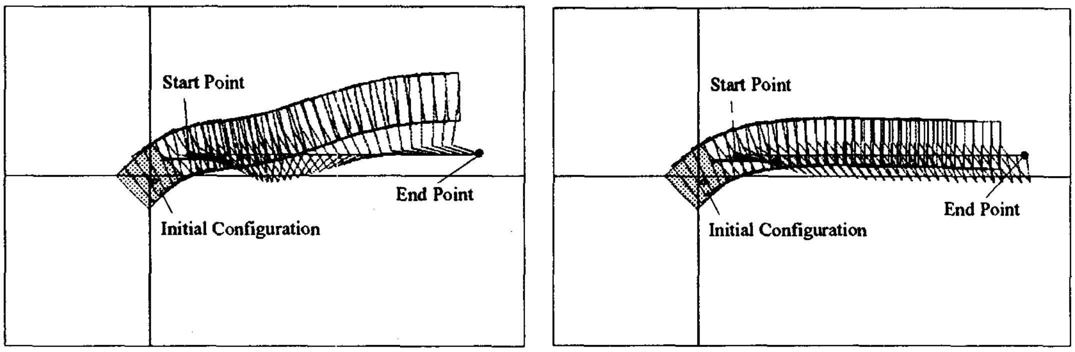


Fig. 3. *Desired and actual end effector trajectories.*



(a) Max. manipulability measure

(b) Min. velocity norm

Fig. 4. *Motion of the mobile robot.*

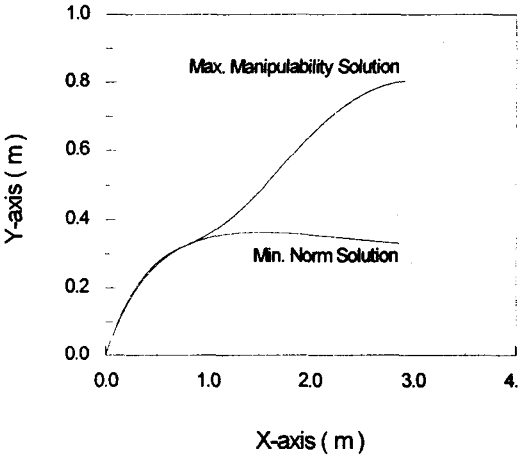


Fig. 5. *Trajectory of the mobile platform.*

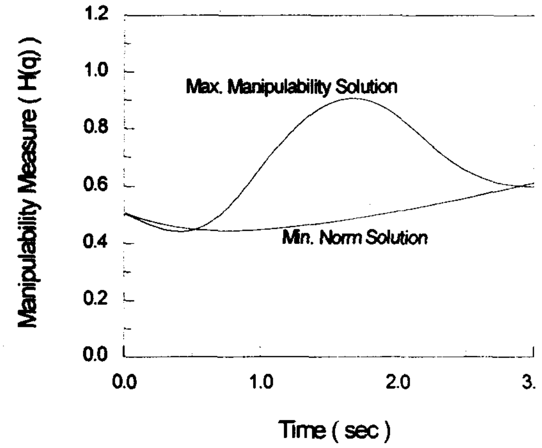


Fig. 6. *Variation of the manipulability measure.*