Mechanics of Advanced and Smart Materials Journal Vol. 1, Issue 1, (2021) 1 – 14

Mechanics of Advanced and Smart Materials Journal

http://masm.araku.ac.ir

Trajectory tracking of an intelligent mobile robot on a slope surface using the nonlinear sliding mode control

M. Nazemizadeh [a*], P. Mallahi kolahi [b]

[a] Faculty of Mechanics, Malek-Ashtar University of Technology, Isfahan, Iran
[b] Faculty of Mechanics, Malek-Ashtar University of Technology, Isfahan, Iran

KEYWORDS

Intelligence robot,
Trajectory Tracking,
Sliding mode control,
Slope surface.

ABSTRACT

Wheeled mobile robots have many applications due to their advantages such as wide workspace, mobility and maneuverability. Intelligence of mobile robots to perform autonomous movements is also one of the favorite fields of robotics researches. In this paper, the trajectory tracking of an intelligent mobile robot on a sloping surface is studied using a nonlinear sliding mode control. First, the nonlinear dynamic equations of a wheeled mobile robot are derived on a sloping surface using the Newton-Euler method. A multistage nonlinear control block is then proposed for trajectory tracking. First, the controller calculates the linear and angular velocity of the robot to find the position of the robot, and then, assuming uncertainties in the dynamic model, a sliding model controller is used to track the robot's specific path. Various simulations are presented to validate the control method, which the results show the capability and efficiency of the proposed method.

1. Introduction

The autonomous and intelligent wheeled mobile robots are widely implemented in hazardous environments. Therefore the autonomous mobile robots have attracted many interests of robotic researchers and several closed-loop control methods are developed to make them autonomous such as: optimal control [1-2], feedback linearization control [3] and robust control [4].

Corradini and Orlando [5] proposed a discrete time sliding mode approach to control mobile robots with uncertainties. They developed a dynamical model and verified the obtained results with experimental data. Korayem et al. [6] presented optimal point-to-point motion planning of non-holonomic mobile robots in the presence of multiple obstacles. They employed the optimal control method to path planning of the robot.

In this paper, the trajectory tracking of an intelligent mobile robot on a sloping surface is studied using a nonlinear sliding mode control. First, the nonlinear dynamic equations of a wheeled mobile robot are derived on a sloping surface using the Newton-Euler method. A multistage nonlinear control block is then proposed for trajectory tracking. First, the controller calculates the linear and angular velocity of the robot to find the position of the robot, and then, assuming uncertainties in the dynamic model, a sliding model controller is used to track the robot's specific path. Various simulations are presented to validate the control method, which the results show the capability and efficiency of the proposed method.

2. Methodology

In this section, the dynamic equations of the mobile robots are derived considering nonholonomic constraints. Fig. 1 shows the mobile robot on a slope:

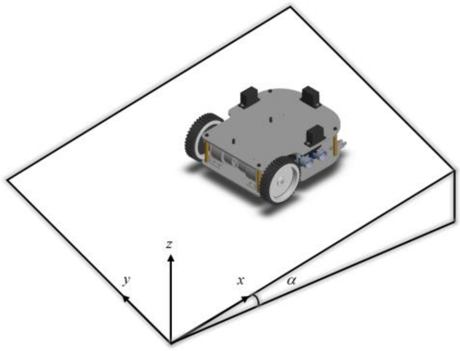

Fig 1. The nonholonomic mobile robot on the slope

Dynamic equations are extracted using the Newton-Euler principle. By defining the coordinate vector $\vec{q} = [x_c \quad y_c \quad \varphi \quad v \quad \omega]^T$, the robot constraint matrix is obtained as follows:

$$A = [\text{Cos}\varphi \quad -\text{Sin}\varphi \quad 0] \tag{1}$$

The general form of the dynamic equations of the system is expressed in the final form as follows:

$$M(\vec{q})\ddot{\vec{q}} + \vec{G}(\dot{\vec{q}}, \vec{q}) = B\vec{\tau} + A\vec{\lambda} \tag{2}$$

The parameters of the above equation are defined as: q is the vector of generalized coordinates and M is the positive definite mass and inertial matrix, G is the vector of Coriolis and centrifugal forces, B is Input coefficient matrix, τ is torque vector, A is the matrix of kinematics constraints coefficients and λ is the vector of Lagrange multipliers. According to equation (2), matrices M, G, B in the motion equation of the mobile robot can be expressed as follows:

* M. Nazemizadeh. Tel.: +98-9127376322
E-mail address: nazemi@mut-es.ac.ir
DOI: 10.29252/masm.1.1.1
Received: September 09, 2021; Received in revised form: September 30, 2021; Accepted: October 01, 2021

$$M = \begin{bmatrix} m & 0 & 0 \\ 0 & m & 0 \\ 0 & 0 & I \end{bmatrix} \quad (3)$$

$$G = \begin{bmatrix} mg\,Sin(\alpha) \\ 0 \\ 0 \end{bmatrix} \quad (4)$$

$$B = \frac{1}{r}\begin{bmatrix} Cos\varphi & Cos\varphi \\ Sin\varphi & Sin\varphi \\ \frac{L}{2} & -\frac{L}{2} \end{bmatrix} \quad (5)$$

In order to remove the Lagrangian coefficient vector from the system dynamic equations (2), the velocity vector $\vec{v} = [v \quad \omega]^T$ and the matrix S are defined with properties $A.S = 0$ and $\dot{\vec{q}} = S\vec{v}$. The null space matrix A is obtained as follows:

$$S = \begin{bmatrix} Cos\varphi & 0 \\ Sin\varphi & 0 \\ 0 & 1 \end{bmatrix} \quad (6)$$

The dynamic equation of the system is expressed by removing the Lagrangian coefficients as follows:

$$\vec{\tilde{M}}(\vec{q})\dot{\vec{q}} + \vec{\tilde{G}}(\dot{\vec{q}}, \vec{q}) = \tilde{B}\vec{\tau} \quad (7)$$

in which parameters can expressed as follows:

$$\vec{\tilde{M}}(\vec{q}) = S^T M S \quad (8)$$

$$\vec{\tilde{G}}(\dot{\vec{q}}, \vec{q}) = S^T(M\dot{S}v + G) \quad (9)$$

$$\tilde{B} = S^T B \quad (10)$$

The controller structure used for the robot on a sloping surface is shown in Fig 2.

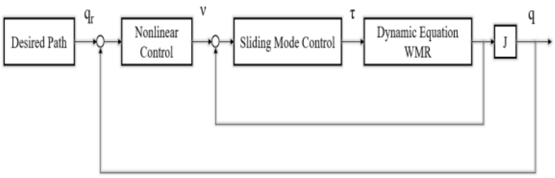

Fig 2. Block diagram of a non-linear control system

In order to obtain the control law required to trajectory tracking by the nonlinear control method, the Lyapunov candidate (11) is expressed as follows:

$$V = \frac{1}{2}(x_e^2 + y_e^2) + (1 - Cos\varphi_e)/K_y \quad (11)$$

The control law is extracted as follows:

$$v_d = v_r Cos\varphi_e + K_x x_e \quad (12)$$

$$\omega_d = \omega_r + v_r(K_y y_e + K_\varphi Sin\varphi_e) \quad (13)$$

In order to design a controller for robot dynamics by sliding mode control method, the sliding surface is defined as follows:

$$S(t) = \begin{bmatrix} s_1(t) \\ s_2(t) \end{bmatrix} = \begin{bmatrix} e_1(t) \\ e_2(t) \end{bmatrix} + \begin{bmatrix} \beta_1 \int_0^t e_1(\tau)d\tau \\ \beta_2 \int_0^t e_2(\tau)d\tau \end{bmatrix} \quad (14)$$

The torque control law in order to control the dynamics of the robot is obtained as follows:

$$\tau = \tilde{B}^{-1}\left(\tilde{M}(\dot{q}_{desired} + \beta e + \varepsilon\,\mathrm{sgn}(s)) + \tilde{G}\right) \quad (15)$$

3. Discussion and Results

In this section, the intelligent robot will be simulated on a sloping surface using the obtained control law. Also, the physical characteristics of the robot are given in Table 1.

Table 1. Intelligent mobile robot parameters

Robot parameters	value	unit
Mass of the robot	m=4	Kg
Moment of inertia	J=2.5	Kg.m^2
Radius of wheel	r=0.03	m
The distance between the wheels and the center of the robot	b=0.15	m
Surface angle	20	deg

The torque required to track the straight path, on surface with different slope:

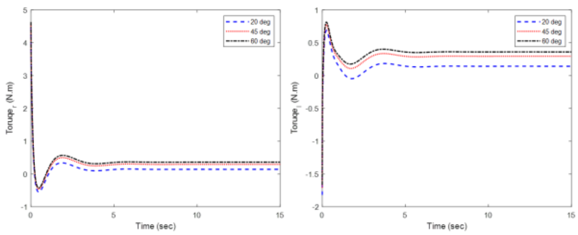

Fig 3. The input torques of the wheels

Also the torque required to track the sine path, on surface with different slope:

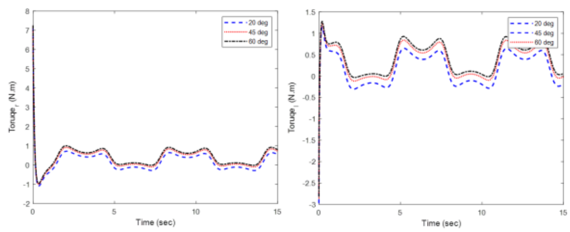

Fig 4. The input torques of the wheels

In both simulations, by tracking different paths, the torque of the wheels increases in order to track the track by increasing the angle of the slope.

4. Conclusions

The purpose of this paper was to trajectory tracking of the intelligent mobile robot over the sloping surface with consideration of the parametric uncertainty of the intelligent robot. For this purpose, first the dynamic equations of the intelligent robot have been extracted by Newton-Euler method with considering the motion constraints. In order to control the robot, in the kinematic part, a nonlinear control was used to achieve the desired linear and angular velocity, and in the dynamic part of the robot, along with considering parametric uncertainties in the model, a sliding model control was used to track the desired path. The simulation results for various trajectory show the efficiency and robustness of the proposed method.

5. References

[1] Korayem M H, Nazemizadeh M, Nohooji H R. Smooth jerk-bounded optimal path planning of

tricycle wheeled mobile manipulators in the presence of environmental obstacles. International Journal of Advanced Robotic Systems. 2012;9:105.

[2] Korayem M H, Nekoo S R, Korayem A H. Finite time SDRE control design for mobile robots with differential wheels. Journal of Mechanical Science and Technology. 2016;30:4353-4361.

[3] Korayem M H, Yousefzadeh M, Manteghi S. Dynamics and input–output feedback linearization control of a wheeled mobile cable-driven parallel robot. Multibody System Dynamics. 2017;40:55-73.

[4] Roy S, Nandy S, Kar I N, Ray R, Shome S N. Robust control of nonholonomic wheeled mobile robot with past information: Theory and experiment. Proceedings of the Institution of Mechanical Engineers, Part I: Journal of Systems and Control Engineering. 2017;231:178-188.

[5] Corradini M L, Orlando. Control of mobile robots with uncertainties in the dynamical model: a discrete time sliding mode approach with experimental results. Control Engineering Practice. 2002;10:23-34.

[6] Korayem M H, Nazemizadeh M, Nohooji H R. Optimal point-to-point motion planning of non-holonomic mobile robots in the presence of multiple obstacles. Journal of the Brazilian Society of Mechanical Sciences and Engineering. 2014;36:221-232.