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Theoretical study of the dynamic characteristics for a hybrid mobile robot

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Abstract

The work offers a theoretical analysis of the dynamic properties of a hybrid mobile robot. A series of parallel and chain connections make up the robot, creating a hybrid system with a mobile platform for movement and a gambit arm for manipulation. A separate platform and processor are typically mounted on top of the mobile platform in mobile robotics designs, and this configuration has the ability to support simultaneous movement, processing, and exchange.

A systematic mathematical model of an eight-wheel, skid-steering mobile robot is presented. The robot is viewed as a subsystem made up of driving, dynamic, and kinematic levels.

1.Introduction

The area of mobile robotics has attracted a lot of attention lately. The description of the kinetic models of mobile robots is a topic of much investigation. Due to the sturdy mechanical design of these wheeled robots, also known as slide steer mobile robots, they are regarded as all-terrain vehicles. These robots are versatile and can operate in a variety of settings and locations. Different steering wheel pairs are used to control the robot's direction on each side. Although the steering technique has some technical advantages, it is difficult to manage the robot since the wheels need to glide laterally in order to follow a curved course. if the vehicle's instantaneous center of rotation (ICR) along the longitudinal axis exhibits a considerable projection. Skidding can cause the vehicle to lose stability. If merely the non-slip assumption is true, however, this phenomena does not matter for ordinary composites.

The dynamic and kinematic model of the eight-wheeled robot may be found below, where we will also examine the robot's motion. We'll make the following assumptions to help decompose the mathematical equations. [1,2]

• Movement takes place on a flat surface; robots' angular and linear velocities are generally low; and the location at which the wheels make contact with the ground is where the wheels' shape is least likely to distort.

• The robot's center of gravity is fixed since the arm is fixed.

• The value of the wheel's speed on the same side is constant.

• There is barely any stickiness between the wheels and the ground.

2. Dynamic model

Figure (1) shows the forces acting on the wheel and the effect of gravity. The active force Fi and reactive force R_i are related to the wheel torque and gravity, respectively. It is clear that Fi is linearly dependent on the wheel control input τi , namely,

$Fi=\frac{\tau i}{r}$ (1)

The blocks are distributed in the moving robot base so that the weight is evenly distributed over the wheels. If the mass of the base mp So it will be the reaction that result from it on each wheel[3]

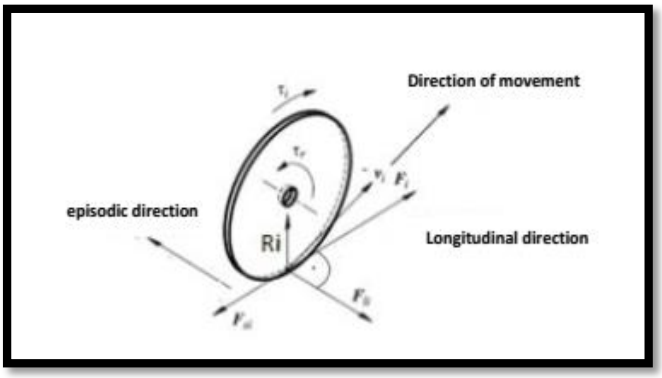

Figure (1): Forces acting on the wheel

$R_{pi} = \frac{m_p g}{8}$ (2)

remains The calculation of the reaction resulting from the influence of the mass of the arm ($2m_a$) (Figure (2)), by taking symmetry into consideration and by neglecting the weight of the base, and by substituting the force of gravity resulting from the weight of the arm and affected its center of gravity with a force and torque affecting the point p_a and by projecting on the Z axis we find[3]

$mag = Ra1 + Ra2 + Ra3 + Ra4$ (3)

From balance about point $P1$:

$mag(3L+D) - Ma - 3LRa4 - 2LRa3 - LRa2 = 0$ (4)

From balance about point $P4$:

$mag\text{D} - Ma + 3LRa1 + 2LRa2 + LRa3 = 0$ (5)

balance about point P_a

$(3L + D)Ra1 + (2L + D)Ra2 + (L + D)Ra3 + DRa4 = Ma$ (6)

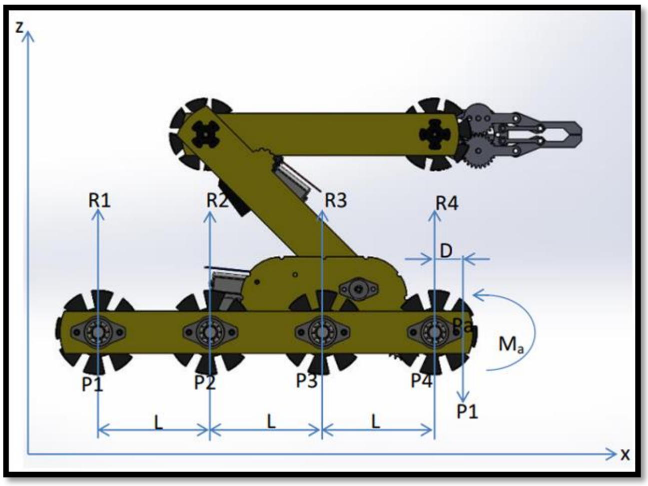

Figure (2): Reactions on the wheels

By solving equations (3) (4) (5) (6) , we find:

$Ra4 = Ra8 = \frac{m_a g(5L+D) - Ma}{3L}$

$Ra3 = Ra7 = 2mag$

$Ra2 = Ra6 = 2mag$ (7)

$Ra1 = Ra5 = \frac{\mathrm{Ma}-\mathrm{m_a g(7L+D)}}{3L}$

And From (2) and (6) we find that the reactions applied to wheels are given by the following equations:

$R_4 = R_8 = \frac{\mathrm{m_a g(5L+D) - Ma}}{3L} + \frac{\mathrm{m_p g}}{8}$

$R_3 = R_7 = 2mag + \frac{\mathrm{m_p g}}{8}$ (8)

$R_2 = R_6 = 2mag + \frac{\mathrm{m_p g}}{8}$

$R_1 = R_5 = \frac{\mathrm{Ma}-\mathrm{m_a g(7L+D)}}{3L} + \frac{\mathrm{m_p g}}{8}$

The force resulting from friction is divided into two components, the first Fsi resulting from the rotation of the wheel and the second Fli resulting from the accidental slip of the wheels .

By applying the Lagrange-Euler equation we find:[4]

$L(q,\dot{q}) = E(q,\dot{q}) + P(q)$

And since the movement is flat, it will be $P(q)$=0

And therefore

$L(q,\dot{q}) = E(q,\dot{q})$

By neglecting the energy produced by the rotation of the wheels, the kinetic energy is given by the following relationship: [4]

$E = \frac{1}{2} m\, \mathrm{v}^T \mathrm{v} + \frac{1}{2} \mathrm{I}\, \dot{\theta}^2$

Where m the mass of the robot and I the torque of the robot about its center of gravity. The previous equation can be written as follows

$E = \frac{1}{2} m(\dot{\mathrm{X}}^2 + \dot{\mathrm{Y}}^2) + \frac{1}{2} \mathrm{I}\, \dot{\theta}^2$ (9)

By calculating the partial derivative of the kinetic energy and then the time derivative we find[4]

$$\frac{d}{\mathrm{dt}}\left(\frac{\partial \mathrm{E}}{\partial \dot{\mathrm{q}}}\right) = \begin{bmatrix} \mathrm{m}\ddot{\mathrm{X}} \\ \mathrm{m}\ddot{\mathrm{Y}} \\ \mathrm{I}\ddot{\theta} \end{bmatrix} = M\ddot{\mathrm{q}} \qquad (10)$$

Where [5]

$$M = \begin{bmatrix} \mathrm{m} & 0 & 0 \\ 0 & \mathrm{m} & 0 \\ 0 & 0 & I \end{bmatrix}$$

From Figure (3) the resultant of the resistive force is given by the following relationship [4]

$$F_{rx}(\dot{\mathrm{q}}) = \cos\theta \sum_{i=1}^{8} F_{si} - \sin\theta \sum_{i=1}^{8} F_{li} \qquad (11)$$

$$F_{ry}(\dot{\mathrm{q}}) = \sin\theta \sum_{i=1}^{8} F_{si} - \cos\theta \sum_{i=1}^{8} F_{li} \qquad (12)$$

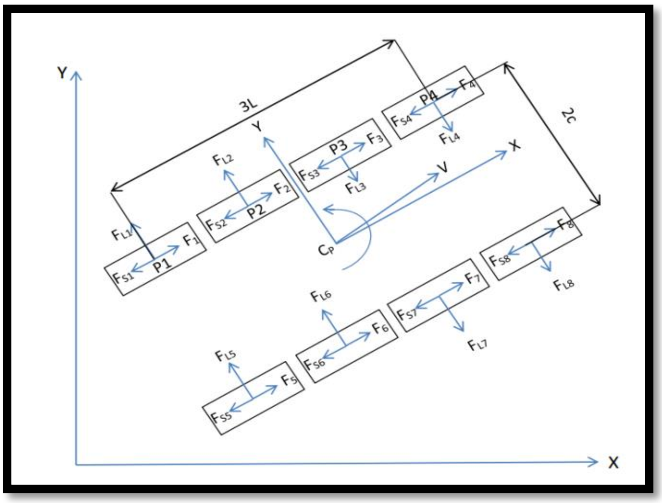

Figure (3): The resistance forces acting on the wheels

$$\boldsymbol{M}_{\mathbf{r}}(\dot{\mathbf{q}}) = (\mathbf{a}-\mathbf{3L}) \sum_{\mathbf{i=1,5}} \mathbf{F_{li}}\left(\mathbf{v_{yi}}\right) + (\mathbf{a}-\mathbf{2L}) \sum_{\mathbf{i=2,6}} \mathbf{F_{li}}\left(\mathbf{v_{yi}}\right) + (\mathbf{a}-\mathbf{L}) \sum_{\mathbf{i=3,7}} \mathbf{F_{li}}\left(\mathbf{v_{yi}}\right) + \mathbf{a} \sum_{\mathbf{i=4,8}} \mathbf{F_{li}}\left(\mathbf{v_{yi}}\right)$$
$$+\,\mathbf{c}\left[-\sum_{\mathbf{i=1}}^{\mathbf{4}} \mathbf{F_{si}}\left(\mathbf{v_{xi}}\right) + \sum_{\mathbf{i=5}}^{\mathbf{8}} \mathbf{F_{si}}\left(\mathbf{v_{xi}}\right)\right] \qquad \mathbf{(13)}$$

The general shape of the vector of resistance force[3,4]

$R(\dot{q}) = [F_{rx}(\dot{q}) \quad F_{ry}(\dot{q}) \quad M_r(\dot{q})\,]^T$ (14)

The robot moves under the influence of the effective force provided by the motors, which is expressed by:

$$F_x = \cos\theta \sum_{i=1}^{8} F_i \qquad (15)$$

$$F_y = \sin\theta \sum_{i=1}^{8} F_i \qquad (16)$$

The effective torque about C is

$M = c(-F_1 - F_2 - F_3 - F_4 + F_5 + F_6 + F_7 + F_8)$ (17)

Thus the vector of effective force is of the form:

$F = [Fx \quad Fy \quad M]$

From equations (13) (14) (15) we find [3,4]

$$F = \frac{1}{r}\begin{bmatrix} \cos\theta \sum_{i=1}^{8} \tau_i \\ \sin\theta \sum_{i=1}^{8} \tau_i \\ c(-\tau_1 - \tau_2 - \tau_3 - \tau_4 + \tau_5 + \tau_6 + \tau_{67} + \tau_8) \end{bmatrix} \qquad (18)$$

To simplify the equations, we know the control input torque as follows

$$\tau = \begin{bmatrix} \tau_L \\ \tau_R \end{bmatrix} = \begin{bmatrix} \tau_1 + \tau_2 + \tau_3 + \tau_4 \\ \tau_5 + \tau_6 + \tau_7 + \tau_8 \end{bmatrix} \qquad (19)$$

Where τ_L and τ_R are the torque produced by the left and right wheels, respectively

And From equations (16) and (17) we have:

$$F = B(q)\tau \qquad (20)$$

Where (B) is the transformation matrix and is defined as follows

$$B(q) = \frac{1}{r}\begin{bmatrix} \cos\theta & \cos\theta \\ \sin\theta & \sin\theta \\ -c & c \end{bmatrix}$$

Using equations (8)(12)(18) we find the dynamic model of the robot

$M(q)\ddot{q} + R(\dot{q}) = B(q)\tau$ (21)

By introducing transverse slip using Lagrange multipliers The equation looks like this:

$M(q)\ddot{q}+R(\dot{q}) = B(q)\tau + A^{T}(q)\lambda$ (22)

For the sake of control, it is better to express equation (20) in terms of the velocity vector η, so we multiply both sides of it from the left by S^{T} (q), so we find

$S^{T}(q)M(q)\ddot{q} + S^{T}(q)R(\dot{q}) = S^{T}(q)B(q)\tau + S^{T}(q)\,A^{T}(q)\lambda$

$\dot{q} = S(q)\eta$ (23)

By calculating the time derivative of equation (23), we find

$\ddot{q} = \dot{S}(q)\eta + S(q)\eta$ (24)

Using equations (20) (21) (23) the dynamic equation becomes [3,4]

$\overline{M}\dot{\eta} + \overline{C}\eta + \overline{R} = \overline{B}\tau$ (25)

Where

$$\overline{C} = S^{T}M\dot{S} = mx_{CR}\begin{bmatrix} 0 & \dot{\theta} \\ -\dot{\theta} & \dot{x}_{CR} \end{bmatrix}$$

$$\overline{M} = S^{T}MS = \begin{bmatrix} m & 0 \\ 0 & mx_{CR}^{2} + I \end{bmatrix}$$

$$\overline{R} = S^{T}R = \begin{bmatrix} F_{rx}(\dot{q}) \\ x_{CR}F_{ry}(\dot{q}) + M_{r} \end{bmatrix}$$

$$\overline{B} = S^{T}B = \frac{1}{r}\begin{bmatrix} 1 & 1 \\ -c & c \end{bmatrix}$$

8. Conclusion

This paper offers a mathematical analysis of the dynamic properties of a hybrid mobile robot. It covers both the research of the robot's stability and the examination of the dynamic model. This design strategy, along with other design innovations and built-in qualities of the demonstrated robot, offer solutions to a number of issues pertaining to the design of mobile robots that can function on uneven terrain, in dangerous environments, as well as both indoor and outdoor artificial environments. The suggested strategy focuses on the operational performance of the system as a whole and is a systematic, useful design and development procedure.

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