DYNAMIC MODELLING AND CONTROL OF WHEELED MOBILE ROBOT

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ABSTRACT

This research study is on the dynamic modelling and control of wheeled mobile robots including friction as a main factor of consideration. Most of the researches in recent years are though focused on the design and development of control techniques and kinematic models for the localization and navigation of wheeled mobile robots, the models are only valid with low speed, low acceleration and light weight. In order to move at higher speed and perform heavy duty work, dynamic modelling of wheeled mobile robot has to be considered. The wheeled mobile robot of our research work is a rigid body with two wheels and a castor that includes control mechanism of friction in order to improve the performance.

***Key words*:** Wheeled mobile robot, Dynamic, modelling, Friction, adaptive control

1. INTRODUCTION

Mobile robotics is a fast evolving and solution oriented research area, which plays an important role in industries including manufacturing, agriculture, aerospace, mining and medicine. The mobile robots have the capability to move around in the environment with limited human interaction. With the changes in the environment, the behavior of the wheeled mobile robots varies and in order to keep the desire of changes minimum, there had been researches done on the related platform. Gracia et al.[1] carried out a comprehensive analysis on the kinematic control of different mobile robots such as omnidirectional and differential-drive. However, a design of low level dynamic control with coupled actuators was required for better performance. The closest study to ours was done by Maung et al.[2] in which he has considered both the analysis of kinematics and dynamics of mobile robots. Neal et al.[3] presented a straight forward, algorithmic method to construct the kinematic models for any articulated wheel mobile robot configuration. However friction has not been considered in a greater level in the above research works. Due to the variation of environmental conditions, friction affects the motion of robot in a greater extend. Wang et al. [5] has proposed a digital acceleration control method in order to model the system. However these controllers are only effective with bounded friction and do not consider about the centre of gravity.

In this paper, we utilize both kinematic and dynamic modelling along with the consideration of friction model. Comparisons between the actual system model and mathematical model through experiments and related results are verified in order to minimize the error percentage. The basic study on friction as well as modelling of the mobile robot has been done and consideration of slippage factor and creation of simulator for the whole system are considered to be done in future.

2. METHODOLOGY

2.1. Robot Model

The robot is modelled as a three dimensional rigid object having a cubic shape with uniform density to ease the mathematical analysis. By using this general model, the mass, inertia and the centre of gravity of the entire body of the robot can be obtained. Figure 1 shows the 3D model of the built robot using solid works tool.

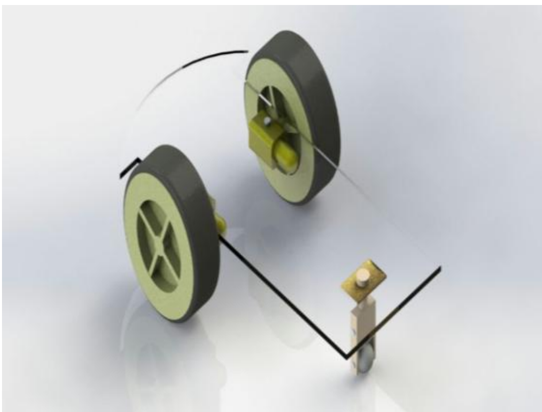

Figure 1: A 3D model of the robot

2.2. Kinematic Model

Kinematic modelling is generally done with the assumption of no occurrence of slippage in the lateral and longitudinal direction so that the system inputs are solely the angular velocities of right and left wheel ω_r and ω_l respectively. The robot motion is determined by the position and orientation of the robot as the location and orientation of the centre of gravity p(Xo, Yo, θo) relative to the fixed world frame in this research work to bring reliable results to the actual system. Thus the linear velocities of the right wheel and left wheel can be expressed as:

$$v_r = R_t\, \omega_r\, \hat{\imath} \qquad (01)$$

$$v_l = R_t\, \omega_l\, \hat{\imath} \qquad (02)$$

Thus the equation of motion of the rigid cart with respect to each wheel is

$$V_R = V_g + r\hat{k}\,(-a\,\hat{\imath} - \frac{b}{2}\,\hat{\jmath})$$

$$= u\hat{\imath} + v\hat{\jmath} + r\frac{b}{2}\hat{\imath} - ra\hat{\jmath} \qquad (03)$$

$$V_L = V_g + r\hat{k}\,(-a\,\hat{\imath} + \frac{b}{2}\,\hat{\jmath})$$

$$= u\hat{\imath} + v\hat{\jmath} - r\frac{b}{2}\hat{\imath} - ra\hat{\jmath} \qquad (04)$$

where Vg is the velocity vector of the centre of gravity, p(Xo, Yo, θo), a is the distance from the rear axle to the centre of gravity, b is the distance between the two driving wheels, u, v and r are the forward, the lateral and the yaw velocity respectively. This research work considered the influence of forward, lateral and yaw velocities in the model to bring accurate results in experiments. Using the equations, the full kinematic model can be determined as:

$$u = (\omega_r + \omega_l)\,\frac{R_t}{2} \qquad (05)$$

$$v = (\omega_l - \omega_r)\,\frac{a\,R_t}{b} \qquad (06)$$

$$r = (\omega_l - \omega_r)\,\frac{R_t}{b} \qquad (07)$$

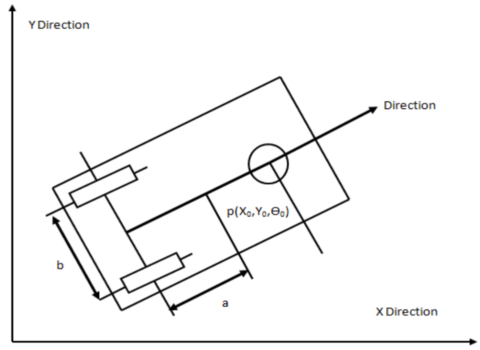

Figure 2: Geometry of the robot

2.3. Dynamic Model

Dynamic model of the three degree of freedom robot which allows movement in the longitudinal and lateral direction along with the angular displacement can be obtained by the consideration of applied forces and moment about the centre of gravity can be expressed as:

$$\sum F_x = m(\dot{u} - vr) \qquad (08)$$

$$\sum F_y = m(\dot{v} - ur) \qquad (09)$$

$$\sum M_z = I_z\,\dot{r} \qquad (10)$$

The applied torque on the robot is the summation of the linear torque to accelerate the robot and the angular torque to accelerate the wheels.

$$T_{app} = T_{lin} + T_{ang} \qquad (11)$$

where T_{app}, T_{lin} and T_{ang} are the applied, linear and angular torques respectively. This linear torque can be converted into a longitudinal force at the wheel / ground interface in this model and expressed as

$$F_X = \frac{T_{lin}}{R_t} \qquad (12)$$

and the angular torque is

$$T_{ang} = I_z\,\dot{\omega} = I_z\,\frac{\dot{u}}{R_t} \qquad (13)$$

$$F_x = \frac{T_{app}\,R_t - I_z\,\dot{u}}{{R_t}^2} \qquad (14)$$

The forces acting on the robot are those forces exerted by the right and left driving wheels and can be expressed as:

$$F_{Xr} = \frac{T_{app}\,R_t - I_z\,\dot{u}_r}{{R_t}^2} \qquad (15)$$

$$F_{Xl} = \frac{T_{app}\,R_t - I_z\,\dot{u}_l}{{R_t}^2} \qquad (16)$$

2.4. Friction Model

Friction acting against the motion can be classified as a static or a kinetic friction where static friction is considered only at zero velocity and represented by its coefficient μ_s as a force threshold F_s which must be overcome to ensure movement. Until reaching this force threshold, the effect of the forces exerted by the wheels are compensated by the static friction force. After overcoming the $F_{s,}$ the robot is set in motion and affected by kinetic friction which is usually represented as a constant Coulomb friction. The kinetic friction model defines the friction at non zero velocities and are independent on the size of contact area and always acts against the motion. In general, the coefficients are defined in terms such that when the coefficient of static friction is higher than the coefficient of Coulomb friction, there is a possibility of stiction effect. Modelling of friction of this research work considering constant coulomb friction and stiction effect are depicted in figure 3 and figure 4 respectively.

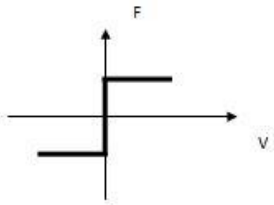

Figure 3: Coulomb friction model

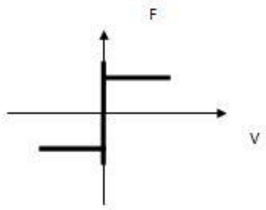

Figure 4: Coulomb friction model with stiction

3. RESULTS

The accuracy of the dynamic model of the system is improved with the addition of friction into the model and thus the robot will not show movement until motors have sufficient force to overcome the threshold force. The simulation experiment, which output is depicted in figure 5 illustrates the effect of acting external force and velocity of the moving object. The inputs of the friction force block are the normal force 10N, the external force F_{ext} is simulated as a sine wave with an amplitude of 1, the linear velocity is same sine signal reduced to half and delayed by one second and the output of the block is the frictional force F_{fr} dependent on inputs and friction coefficients relevant for rolling movement.

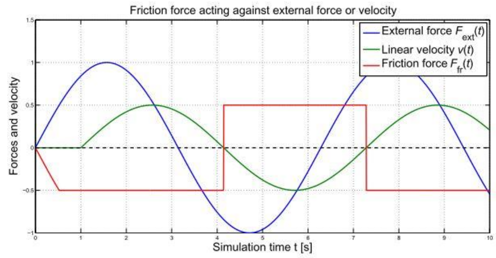

Figure 5: The Coulomb friction results

The block diagram of the mobile robot control system is shown in figure 6. The controller consists of two parts which deals with the dynamic changes in the robot and the changes in the environment in which the robot operates separately. In this strategy, an adaptive motion control algorithm based on self tuning adaptive controller is considered.

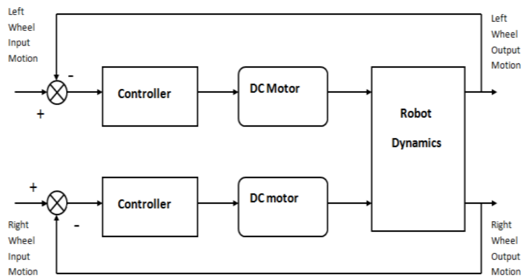

Figure 6: Block diagram of the control system

The hardware model was used to calculate the mass, centre of gravity and the inertia of the system. However, the error percentage is not negligible due to the occurrence of slippage and the mobile robot showed variation with the developed model since the controller was unable to cope up with the changes in the surface conditions.

Table 1: Quantitative Error Analysis

Calculated Friction Coefficient	Actual Friction Coefficient	Error Percentage
0.23	0.2 Wet Wood	15 %
0.48	0.25 – 0.5 Clean Wood	Acceptable

This can be neglected by including a combined controller that can deal with related changes. In addition, consideration of friction model including viscous friction can also reduce the error percentage between the systems.

4. CONCLUSION

A wheel mobile robot system has numerous advantages in the industry environment. They are built in different dimensions according to the applications. It is economically advisable to look for the conditions and parameters that control the motion of these systems. This research paper is the basic work on the simulator to be created that will include slippage and friction models into the system such that the simulated model can be used for the system loading and conditions. The scope of the system is to use a camera to get related images to consider the slippage of the wheels and the data will be input in order to build up the environment.

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