Performance Evaluation of Wheeled Rover by Analysis and Test

Gaurav Sharma, Srividhya G., Shamrao, K. Balaji, G. Nagesh , C.D. Sridhara

Abstract

Rovers provide a mobile platform for exploring planetary bodies. The rover performance on uneven terrain depends on mobility limits on slopes and obstacles which in turn is dictated by the rover configuration. This includes the number of wheels, the dimensions of the rover, wheel size, presence of active joints and the like. In this study, to evaluate the performance of rover on lunar terrain which is uneven and covered with regolith and boulders, benchmark obstacles have been considered that are rigid and regular in shape like inclined and stepped terrain. A quasi-static analysis is carried out where equilibrium equations are solved to obtain the normal contact forces. Subsequently, the friction coefficient required to develop traction to overcome obstacle resistance and the wheel drive torques are obtained. The toppling limits for the longitudinal and lateral directions are also obtained. Consequent to analysis, the rover hardware is tested on benchmark obstacles. To control the rover, an active open loop algorithm has been developed using an external motion controller for the motors used to drive the rover. This study provides a validation to the analytical model besides proving the performance of rover hardware on obstacles.

Keywords: Rover, Traction, Drive torque, CAN, Quasi-static analysis

1 Introduction

Wheeled rovers have been utilized for extra-terrestrial explorations in the past and continue to be preferred for future missions too. Among lunar explorations, Lunokhod-I & II from Russia and Lunar Roving Vehicle (LRV) from U.S.A. have performed well on lunar terrain. Lunokhod-I was an eight wheeled skid steered

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756.0 kg rover with wheel diameter of 51.0 cm. LRV used a four wheeled 280.0 kg manned rover with wheel diameter of 82.0 cm [1].

Unlike earlier missions of the past wherein the rovers were bulky and used large wheels, the future missions are expected to be of low mass with compact design so as to be cost effective. In this regard, countries like India, Canada, China and Japan have revealed definite plans to visit the lunar terrain using lander and rover. Google Lunar X Prize competition has drawn interest among Private Companies worldwide to explore the lunar terrain. Red rover developed by Astrobotic Inc. is one such participating rover of 70.0 kg driven by four rigid wheels of 50.0 cm diameter [2]. AMALIA rover by team ITALIA is a four wheeled 30.0 kg rover utilising flexible wheels of 18.0 cm diameter [3]. A typical rover consists of a chassis supported by a mobility system consisting of links, motor driven wheels with harmonic drive, bearing and resolver [4]. A differential mechanism is usually incorporated to ensure positive contact between the wheel and terrain at all times. The mobility system is critical sub-system of the rover that ensures that the rover traverses over the terrain along commanded path and controls the wheel input so as to keep the wheel slip to a minimum [5].

A four wheeled skid steered rover has been developed. Each wheel is independently driven using brushed D.C. motor with harmonic drive. A differential mechanism is used between the left and right links to ensure positive contact of the wheels with ground. This paper covers the mathematical modelling for the performance prediction of a four wheeled rover on various benchmark obstacles, real-time performance and comparison of results.

2 Mathematical Modelling

The model is based on the assumption that the rover moves at a low speed so that the dynamic effects can be ignored. The wheel is assumed rigid and cylindrical in shape. Equilibrium equations are derived considering the weight of the rover, traction force and normal contact force. The forces are equated along the direction of motion, vertical direction and the moment is equated at the contact point. The rover configuration is shown in Fig. (2.1).

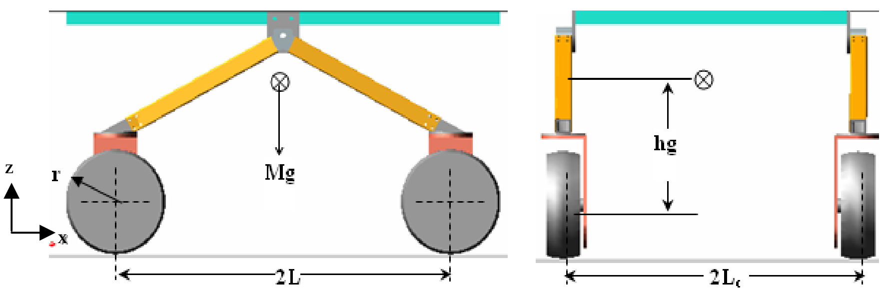

Figure 2.1: Schematic of the rover

Rover wheel radius ‘r’ is 65.0 mm, C.G. location w.r.t. wheel centre ‘h_g’ is 200.0 mm, wheel centre to C.G. distance along X direction ‘L’is 250.0 mm and that along Y direction ‘L_c’ is 110.0 mm & the overall mass of the rover ‘M’ is 16.0 kg. The analysis is carried out considering earth’s gravity.

2.1 Rover moving on Inclined Terrain

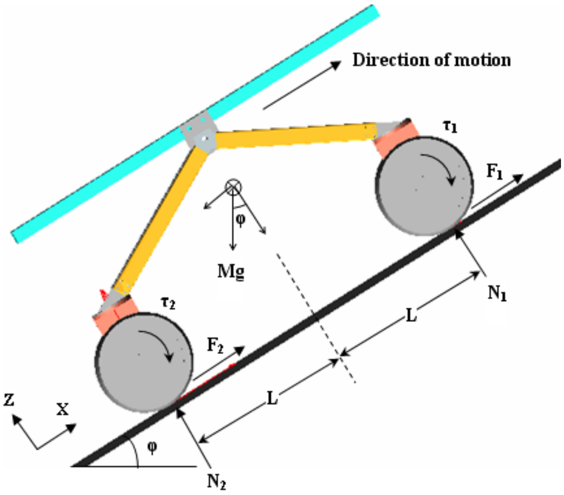

Figure 2.2: Rover traversing up an inclined terrain

Rover traversing up an inclined terrain with ‘φ’ slope is shown in Fig. (2.2). Here, a component of the rover weight acts in opposite direction of motion; hence the normal force at the rear wheel is higher than at the front wheel. Normal force N_1 and N_2 at the front and rear wheel are given by :-

$$N_1 = \frac{Mg}{4}\left\{\cos\varphi - \frac{(h_g + r)\sin\varphi)}{L}\right\} \tag{1}$$

$$N_2 = \frac{Mg}{4}\left\{\cos\varphi + \frac{(h_g + r)\sin\varphi)}{L}\right\} \tag{2}$$

Drive torques are given by:-

$$\tau_1 = \mu_s N_1 r \tag{3}$$

$$\tau_2 = \mu_s N_2 r \tag{4}$$

To avoid the rover from sliding down the slope, a minimum static friction coefficient μ_s of tan (φ) is required. Even if the friction is high enough the rover can topple at a certain angle at which the normal force N_1=0 and the wheel loses contact. For front slope, the topple angle φ_t is 43.0 deg. It calculated as shown in Equation (5).

$$\varphi_t = \tan^{-1}\left\{\frac{L}{h_g + r}\right\} = 43.0\,\text{deg} \tag{5}$$

For the side slope the toppling angle is obtained as 23.0 deg.

2.2 Rover climbing a Small Step

Rover climbing a small step (step height less than the wheel radius) with the front wheel on the obstacle is shown in Fig. (2.3). 'α' is the contact angle defined between the traction force and global 'Z' direction.

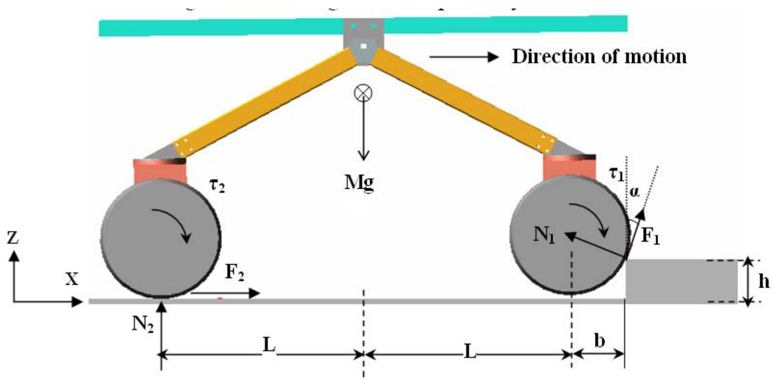

Figure 2.3: Rover climbing a small step (front wheel over step)

When the front wheel climbs the step, the contact forces are given by:-

$$N_1 = \frac{\mu_s Mg(L+b)}{2(2L+b-\mu_s h)(\cos\alpha - \mu_s \sin\alpha)} \tag{6}$$

$$N_2 = \frac{Mg(L+b)}{2(2L+b-\mu_s h)} \tag{7}$$

For a given step height 'h', μ_s is varied iteratively and a value that satisfies the equilibrium of forces at the contact point between the climbing wheel and obstacle is obtained. When the rear wheels climb up the obstacle, the contact forces get modified as shown below:-

$$N_1 = \frac{Mg(L-b)}{2(\mu_s h + 2L - b)} \tag{8}$$

$$N_2 = \frac{\mu_s Mg(L-b)}{2(\cos\alpha - \mu_s \sin\alpha)(\mu_s h + 2L - b)} \tag{9}$$

3 Test Set Up and Results

A four wheeled rover has been developed and tested on standard obstacles viz. slope and step. The wheels are driven by individual brushed DC motor and each wheel houses its own wheel drive module. An active open loop algorithm has been developed using an external motion controller for the motors and is compatible with CANOpen (Controller Area Network) communication interface. The CAN hardware is a PCI based communication interface and supports up to 127 nodes (devices) per network segment with transfer rates up to 1 Mbit/s [7]. Fig. (3.1). shows the connection diagram of the motion controllers (called as nodes) with the wheel motors of the rover and the PC [8].

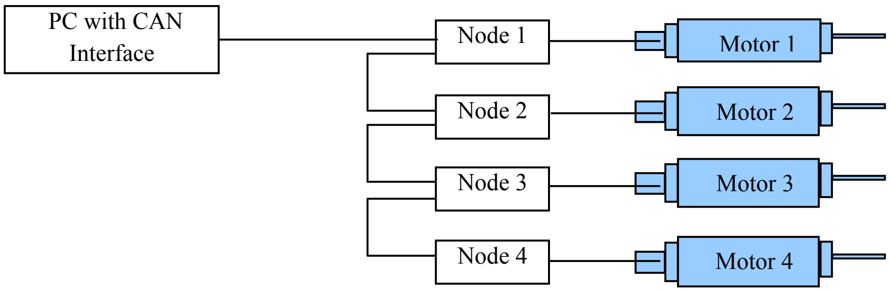

Figure 3.1: Connection diagram of rover with wheel motors

The rover responds to the command from the CAN User interface and performs the drive tasks accordingly. The communication is message-related; each communication object receives its own 11 bit identifier. The software executes one command at a time. For each command a corresponding CAN message frame is available on the channel, enabling the CAN unit to be operated analogously to the serial variant. The current drawn by the driving motors are monitored individually, stored and converted to torque from motor torque-current characteristics. In Fig. (3.2), the motor torque-current characteristics are shown.

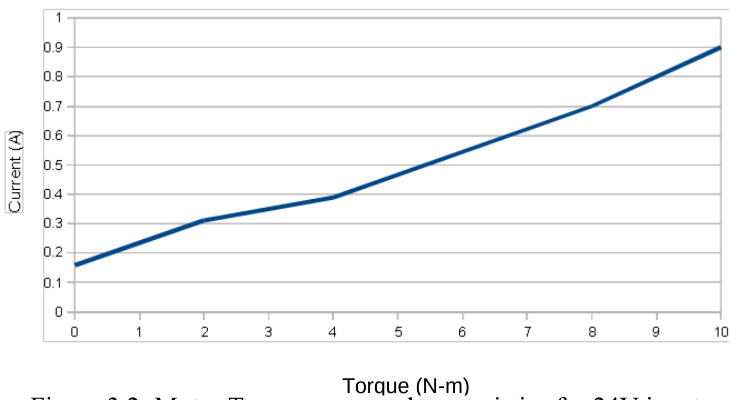

Figure 3.2: Motor Torque-current characteristics for 24V input

3.1 Rover Performance on flat and inclined surface

The rover is moved on a flat surface on hardboard with zero inclination and on a 25 deg slope. The plots of the motor current are shown in Fig. (3.3) and Fig. (3.4) respectively.

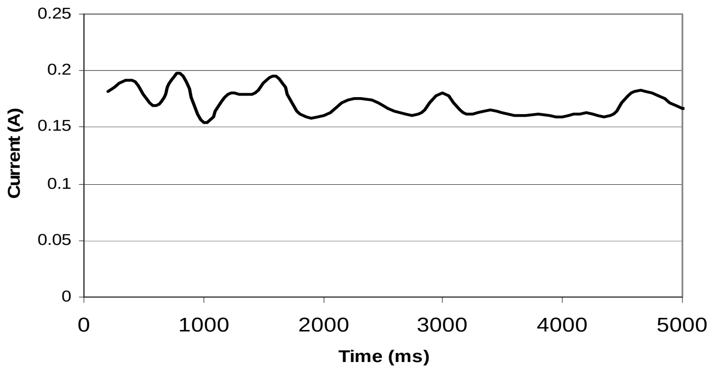

Figure 3.3: Motor current variation on a flat surface

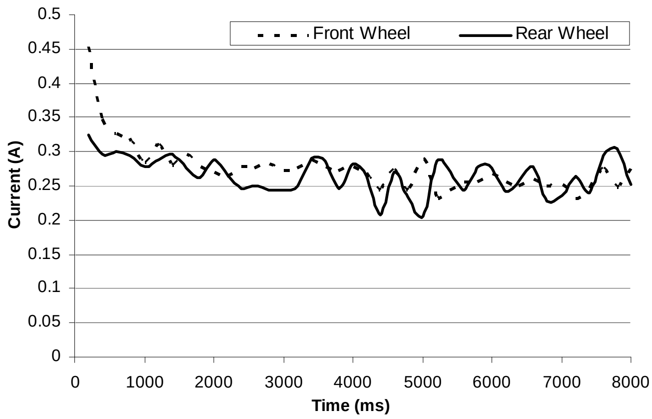

Figure 3.4: Motor current variation for the front & rear motor on an inclined surface

Average current drawn by individual motor for flat surface is 0.182A. For a 25 deg slope, average current drawn by front motor and rear motor is almost same i.e. 0.26A.

3.2 Rover Performance on a Step

The rover is moved over a step of 40 mm resting over hardboard. The current drawn by the front and rear motor when the front wheel climbs the obstacle are shown in Fig. (3.5). The current drawn by the front and the rear motor when the rear wheel climbs the obstacle are shown in Fig. (3.6)

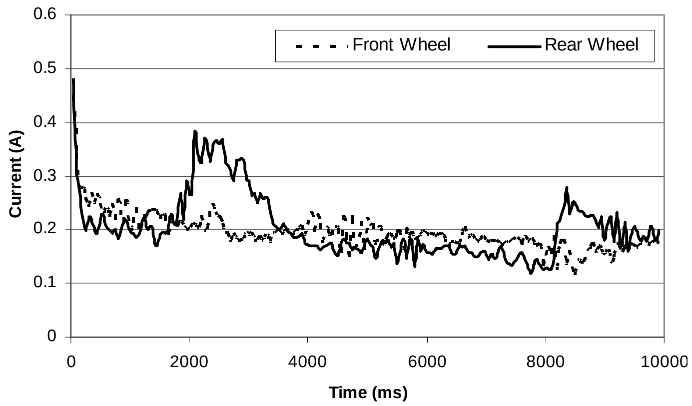

Figure 3.5: Motor current variation in front/ rear motor (front wheel climbs the step)

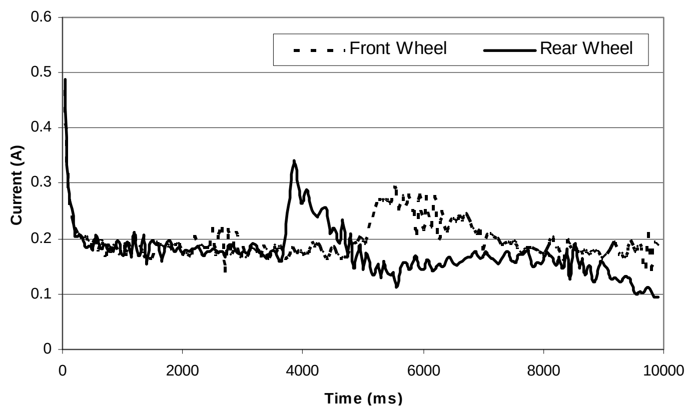

Figure 3.6: Motor current variation in front/rear motor (rear wheel climbs the step)

From the graphs shown above, peak current is observed when the wheel just lifts over the obstacle. When the front wheel climbs, the current drawn by the front motor is 0.22A and that by the rear motor is 0.37A. When the rear wheel (RW) climbs it is 0.28A for front motor and 0.35A for rear motor. The torques corresponding to all these current values are summarised in Table-3.1. The analytically estimated values are also shown for comparison.

Table 3.1: Results Summary

Case.	*Analysis (Nm)*		*Test (Nm)*	
Inclined	*FW*	*RW*	*FW*	*RW*
	0.58	*1.58*	*1.5*	*1.5*
Step , RW climbing	*1.65*	*2.16*	*1.7*	*3.1*

It is observed that for an inclined terrain, the front and rear wheels have developed same torque whereas analysis predicted more torque in rear wheel than front wheel. This is because in analysis it is assumed that both wheels utilize same amount of friction coefficient to generate traction proportionate to their respective normal forces. In reality, the wheels might have utilized different friction coefficients leading to almost same torques. On a step, when the rear wheel climbs a good match is observed. The test values are higher than the prediction due additional rolling resistance that the wheels overcome besides the obstacle resistance.

4 Conclusions

An analytical model has been developed for the characterization of a four wheeled rover. Using this model, the friction and torque requirements for standard obstacles have been obtained. A rover hardware has been realised which is controlled by in-house developed software. The rover is tested on standard obstacles like slope, step and a good match is observed between the predicted values and test results. With this study, the modelling of the mobility system is validated and the design parameters like motor torque, wheel diameter have been obtained.

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