The 3rd Joint International Conference on Multibody System Dynamics
The 7th Asian Conference on Multibody Dynamics
June 30-July 3, 2014, BEXCO, Busan, Korea

Analysis of Obstacle Climbing Manoeuvres for Planetary Exploration Rovers

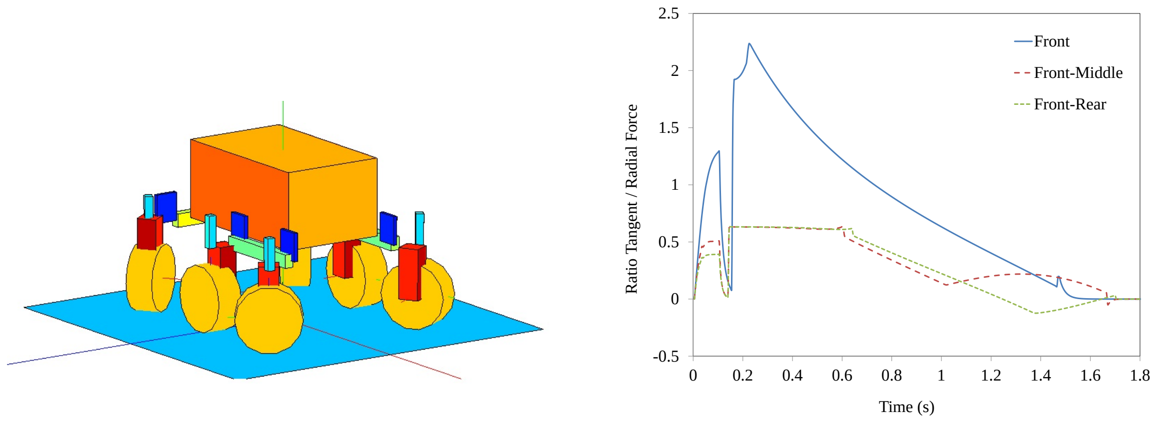
Bahareh Ghotbi, Eric Karpman, Francisco González, József Kövecses, Jorge Angeles

Department of Mechanical Engineering and Centre for Intelligent Machines
McGill University
817 Sherbrooke St. West, H3A 0C3 – Montréal, Québec, Canada
bahareh.ghotbi@mail.mcgill.ca, eric.karpman@mail.mcgill.ca, franglez@cim.mcgill.ca,
jozsef.kovecses@mcgill.ca, angeles@cim.mcgill.ca

Abstract

The definition of performance indicators is a useful tool in the design and operation of planetary exploration rovers. These robots are intended to operate in unstructured environments, often with unknown mechanical properties, which makes it difficult to accurately predict the behaviour of the vehicle in real-world conditions. On the other hand, it is also possible to define performance indicators based on an alternative approach, where the qualitative effect of changes in the design and operation parameters on the performance of the rover becomes the primary goal of the analysis.

The use of performance indicators in the analysis of planetary exploration vehicles was demonstrated in an earlier paper [1]. Wheel radius, vehicle centre-of-mass position, and torque distribution among the wheels were selected as design and operation parameters. The effect of their variation on the performance indicator, i.e. the overall traction developed by the rover, was studied with simulations and experiments. A similar approach was used by Thueer and Siegwart [2], where several performance indicators were defined for a step-climbing manoeuvre. Different vehicle suspension concepts were compared using static analysis in terms of the torque required to climb the obstacle and the ratio between normal and tangent forces at the contact points between wheels and ground.



(a) (b)

Figure 1: (a) Rover model used in simulation and (b) tangent-to-normal force ratio obtained for three different torque distributions, during the negotiation of an obstacle with $H = 0.1$ m

In this work, the above-mentioned research is expanded in order to consider dynamic effects during the negotiation of step obstacles with planetary rovers, which requires major modifications with respect to the static analysis approach. The step climbing manoeuvre can no longer be considered a succession of static equilibrium states; forward-dynamics simulation is needed in the analysis which, in turn, requires the definition of actuation laws to drive the wheels of the vehicle. This way not only different rover configurations, but also actuation strategies can be compared. A simulation test consisting of a wheel rolling on horizontal terrain and climbing a step obstacle of height H was defined for the study. Kinematic specifications were used to model the interaction between wheel and ground, assuming that no slip occurs at the interface. This represents the ideal motion of the rover; it is equivalent to considering that the wheel rolls on the horizontal ground plane and the vertical step walls, and that it revolves around the corner of the obstacle once contact is established at that point. The Rover Chassis Prototype (RCP), a six-wheeled planetary rover, was selected for a series of simulations in which several actuation strategies and suspension designs were assessed. The RCP was modelled using a multibody library written by the authors using MATLAB (Fig. 1a). Both the minimum torque requirement and the ratio between tangent and normal forces at the contacts were selected as performance indicators and evaluated during the climbing manoeuvre of the front pair of the rover wheels. The rover was driven under velocity control, with driving torques applied to the wheels of the rover according to

$$\tau = \min\left(\tau_{max},\, k\left(\omega - \omega_{ref}\right)\right) \quad (1)$$

where τ is the driving torque, ω is the angular velocity of the wheels relative to the suspension frame, ω_{ref} is the desired angular velocity of the wheels, k is a proportional gain, and τ_{max} is the maximum torque that can be delivered by the motor. In this test ω_{ref} was set to 1.2 rad/s, and $k = 100$ Nms.
The minimum torque requirement and the tangent-to-normal force ratio were used to compare several actuation strategies and suspension designs for the RCP. First, the performance of the rover was compared for three different driving torque distributions: powering only the front wheels of the vehicle; powering the front and middle wheels; and powering the front and rear wheels. Results are shown in Fig. 1b. The lower tangent-to-normal force ratio required by the two last torque distributions shows that the front wheel is less likely to slip during the climbing manoeuvre. Additionally, the comparison of the minimum torque requirements showed that actuating both the front and middle wheels is the most efficient of the three case studies, requiring 18 Nm. Actuating only the front wheels would require 33 Nm, whereas powering both front and rear axles would need 24 Nm.

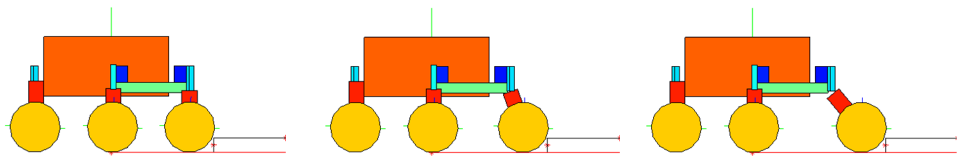


Figure 2: Three configurations of the RCP suspension with different front leg angles: $\theta = 0°$, $\theta = 20°$, and $\theta = 40°$

Second, the angle of the front legs of the RCP with respect to the vertical (θ) was modified to evaluate the effect of this parameter on the climbing ability of the rover (Fig. 2). Table 1 summarizes the results obtained based on the simulation of the manoeuvre for each configuration, highlighting the advantages of configurations with a higher value of θ.

Table 1: Performance indicators obtained during step negotiation for different values of θ

	$\theta = 0°$	$\theta = 10°$	$\theta = 20°$	$\theta = 30°$	$\theta = 40°$
Minimum torque required (Nm)	18	18	17	15	14
Maximum tangent-to-normal force ratio	0.64	0.67	0.68	0.69	0.69

The same approach can be applied to the dynamic analysis of other kinds of obstacles and 3-D manoeuvres, obtaining thus performance indicators that represent a powerful tool to optimize the design and operation of planetary exploration rovers.

References

[1] Ghotbi, B.; González, F.; Kövecses, J.; Angeles, J.: Vehicle-Terrain Interaction Models for Analysis and Performance Evaluation of Wheeled Rovers. In Proc. of the 25th IEEE/RSJ Int. Conf. on Intelligent Robots and Systems (IROS), pp. 3138–3143. Vilamoura, Portugal, 2012.

[2] Thueer, T.; Siegwart, R.: Mobility Evaluation of Wheeled All-Terrain Robots. Robotics and Autonomous Systems, Vol 58, No. 5, pp. 508–519, 2010.