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THE ROLE OF NORMAL FORCE DISTRIBUTION IN ROVER PERFORMANCE

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ABSTRACT

Many applications of wheeled robots include operation in unstructured environments. Optimizing the vehicle mobility is an important goal in the design and operation of rovers on soft soil. Reduced mobility can limit the ability of the robot to achieve the mission goals, and can even render it immobile in extreme cases. The mobility of a wheeled robot depends on its ability to generate a required amount of traction force at the wheel-ground interface while keeping the slip ratio low. Study of the soil reaction forces at the wheel-terrain interface shows that the distribution of total normal load among the wheels influences the net drawbar pull the vehicle is able to provide. The Normal Force Dispersion (NFD) is defined as the standard deviation of the normal reaction forces at the wheel-terrain contact interfaces. The main application of this index is in the assessment and comparison of configurations of the same vehicle on a given type of soil.

Most rover prototypes have a certain degree of reconfigurability, which makes it possible to modify their NFD. The NFD can also be modified by using active suspensions, with the aim of altering the system internal forces by means of actuation on the suspension joints. Simulation and experimental results confirm that of two different configurations of the same vehicle, the one with a more uniform normal load distribution will develop a lower slip to provide the same drawbar pull. This indicator can be used in the design and operation planning of rovers, providing guidelines to change the configuration and actuation on the rover suspension. This will increase the traction at the wheel-terrain interface, thus enhancing the mobility of wheeled robots on soft soil and improving slope climbing maneuvers.

EFFECT OF NORMAL LOADS ON TRACTION

The interaction between a rigid wheel and soft soil under steady-state conditions is commonly modeled using terramechanics relations [1]. Following this approach, the forces at the wheel-terrain interface can be obtained as functions of the state of the vehicle, the angular and translational velocities of the wheels, and a set of parameters that define the nature of the terrain. The terrain normal and tangential reaction forces are evaluated by integrating the normal stress σ and shear stress τ along the surface of wheel-ground contact. The two stresses, however, are related by semi-empirical relations. Shear stress of a point on the perimeter of the wheel in contact with the terrain, with angle θ from the vertical axis, can be determined as

$$\tau(\theta) = [c + \sigma(\theta)\tan\phi]\left[1 - e^{r[\theta_1 - \theta - (1-i)(\sin\theta_1 - \sin\theta)]/K_d}\right] \quad (1)$$

where c is the terrain cohesion, ϕ the internal friction angle, r the wheel radius, K_d the shear deformation modulus, and i the wheel slip ratio, defined as $i = (r\omega - v)/r\omega$. Moreover, θ_1 is the entry angle of the wheel-terrain contact.

The relation between σ and τ is nonlinear, as it includes an exponential term that is, in turn, a function of the slip i. This implies that the relation between normal force and drawbar pull

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is of a nonlinear nature. Wheel slip and soil properties define the exact shape of that curve. Figure 1 illustrates the relation between the amount of drawbar pull a single wheel generates and the terrain normal reaction force for several slip ratios.

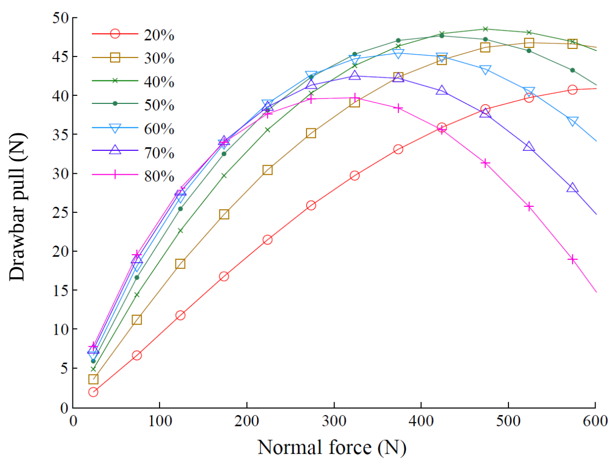

FIGURE 1. DRAWBAR PULL VS. NORMAL LOAD FOR A SINGLE WHEEL WITH DIFFERENT SLIP RATIOS

This study is extended to analyze the mobility of wheeled robots operating on homogeneous terrain. If all the wheels of the vehicle are identical and develop the same slip ratio, it is valid to assume that a single curve can represent the relation between drawbar pull and normal force for all the wheels. In this case, the study of the shape of the curve shows that the maximum total drawbar pull is achieved when the normal load is evenly distributed among the wheels. Therefore, the *Normal Force Dispersion* η is introduced here as a measure of the uniformity of the normal load distribution. This performance indicator is the standard deviation of the normal forces F_n at the wheel-terrain contact interfaces, namely,

$$\eta\left(F_{n1},\ldots F_{np}\right)=\sqrt{\frac{1}{p}\sum_{i=1}^{p}\left(F_{ni}-\mu\right)^2} \tag{2}$$

where p is the number of wheels of the vehicle and μ is the average normal force:

$$\mu=\frac{1}{p}\sum_{i=1}^{p}F_{ni} \tag{3}$$

An even distribution of normal forces ($F_{n1}=F_{n2}=\ldots=F_{np}$) would result in $\eta=0$. Experimental results reported by the authors [2] support the assertion that rover configurations with higher η provide a lower drawbar pull compared to other configurations with lower η, for the same slip ratio.

RESULTS

The foregoing analysis can be used in the design of planetary exploration rovers and in operation planning. The climbing ability of a given rover can be enhanced through modifications in its design and operation parameters. Most rover prototypes can be reconfigured, which makes it possible to modify η. Examples of this are reconfigurable chassis or attached manipulators. This can also be achieved by using active suspensions, which allow for altering the system internal forces by means of actuation forces and torques on the suspension joints.

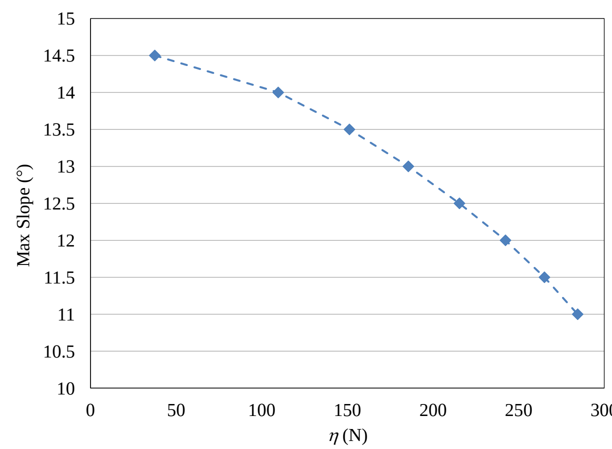

FIGURE 2. CORRELATION BETWEEN THE MAXIMUM SLOPE ANGLE THAT THE RCP CAN CLIMB WITH A 90% SLIP AND THE η INDEX

The simulation results in Fig. 2 show that a correlation exists between the value of η and the maximum slope the vehicle can climb. Lower values of the normal force dispersion resulted in the rover being able to travel on steeper terrain without exceeding a 90% slip.

REFERENCES

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[2] Ghotbi, B., González, F., Kövecses, J., and Angeles, J., 2012. "Vehicle-terrain interaction models for analysis and performance evaluation of wheeled rovers". In IEEE/RSJ International Conference on Intelligent Robots and Systems IROS 2012, pp. 3138–3143.