TRACTION MAXIMIZATION IN MULTI-AXLE WHEELED ROBOTS

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Abstract
Wheeled robotic platforms are advantageous for applications in unstructured environments due to their good stability and manoeuvrability properties. However, the mobility of wheeled robots can be reduced on soft, irregular surfaces. Terrain irregularity may give rise to a very uneven distribution of the robot load among the wheels and excessive sink-age in some wheels. Such situations must be avoided since a rescue mission can be very challenging and in some cases impossible.

One approach to prevent mobile robots from falling into immobilized situations is monitoring the load distribution among the wheels during operation. In addition to enhancement of stability, continuous adjustment of load distribution during motion can improve the overall mobility of the robot throughout the mission.

The mobility of wheeled robots on soft terrain is greatly influenced by the robot ability to generate enough traction at the wheel-terrain interface. The tangential force generated at the wheel-terrain interface is a function of the wheel slip, the normal force, and the wheel and soil properties.

The objective of this work is to find the best normal force distribution among the wheels of the robot for the purpose of generating an overall high traction force. To this end, studying the relation between normal force F_n and developed drawbar pull F_D at the wheel-terrain interface is necessary.

In multi-axle vehicles the terrain properties change after the passage of the front wheels and the successive wheels experience a soil with different properties. Therefore, multi-pass effect must be taken into consideration in the study. A model proposed by Senatore and Sandu [1] is used to represent this effect in simulation of rovers on soft terrain.

In this work we solve a maximization problem to find the set of normal forces that result in the highest total tangential force that the robot can develop. To this end, first, the F_D-F_n curve for the operating conditions of each of the wheels of the rover has to be generated from single wheel simulation or experimental data. For a vehicle with k wheels, the F_D-F_n curve corresponding to wheel i is generated based on the parameters of the soil, wheel slip, and number and condition of previous passes on the soil. Each curve is then approximated by a polynomial, which provides the value of the drawbar pull that each wheel can develop as a function of its normal load: $F_{Di} = f_i(F_n)$. The maximization problem can be formulated as follows:

$$\max_{f_n} \sum_{i=1}^{k} F_{Di} \ \text{ s.t. } \sum_{i=1}^{k} F_{ni} = w_t \ \text{ and } \ F_{Di} > 0 \qquad (1)$$

where $f_n = [F_{n1}, F_{n2}, \ldots, F_{nk}]^T$ is the k-dimensional array of normal forces applied on the wheels of the rover, F_{ni} is the normal force at the i^{th} wheel, and w_t is the total load on the rover that has to be balanced by the terrain normal reactions. This methodology was used to find the optimum normal force distribution of a six-wheeled planetary rover prototype operating on soft soil. Several scenarios with different types of soil and values of wheel slip were considered. For all the studied cases, the simulation results of the straight-line motion of the rover showed that the highest drawbar pull was developed with the normal force distribution obtained by solving the maximization problem.

The optimum load distribution among the wheels depends on the way in which the terrain reaction forces are affected by the multi-pass effect. On terrains for which the multi-pass effect is negligible, an even normal force distribution is advantageous [2]. In contrast, if the passage of the leading wheels produces a strong change on terrain behaviour, then higher drawbar pull will be obtained if the load is partially transferred to the rear wheels. The passage of the leading wheels results into an increase in the soil compaction and this improves the ability of the rear wheels to develop drawbar pull. However, the exact amount of the load transfer differs based on the operation conditions and that brings the need to solve the maximization problem for each scenario. This study can also be applied to wheeled robots operation on non-homogeneous terrain.

Keywords: multi-pass, mobile robot, normal force distribution
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[1] Senatore, C., and Sandu, C., 2011. "Off-road tire modeling and the multi-pass effect for vehicle dynamics simulation". Journal of Terramechanics, 48(4), pp. 265–276.

[2] Ghotbi, B., Gonzalez, F., Kovecses, J., and Angeles, J., 2014. "Effect of normal force dispersion on the mobility of wheeled robots operating on soft soil". In Proceedings of the 2014 IEEE International Conference on Robotics and Automation (ICRA).