Vehicle-Terrain Interaction Model for Analysis and Performance Evaluation

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Abstract

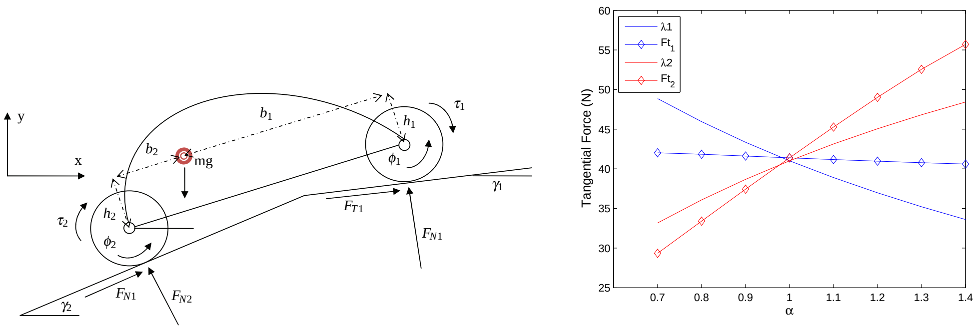
Mobile robots are currently one of the best candidates for planetary surface explorations, due to their good performance in unstructured environments. However, the robots are required to be very robust to environmental uncertainties when it comes to semi-autonomous missions. A major source of uncertainty in planetary applications is the vehicle-terrain interaction. The analysis of this complex phenomenon poses serious difficulties and proposed terramechanics models are only helpful in capturing the behaviour of the vehicle under some restrictive assumptions [1]. For many analysis purposes, such as sensitivity analysis, estimating the effect of change in system parameters on the overall change of a performance indicator is the primary objective; the precise value of the performance indicator being secondary. This was the motivation for proposing a model which is parametric and captures certain behaviours of the physical system; the behaviours that are important for performance evaluation of the system. Therefore, the outcome of the parametric studies, if proven to be consistent with the behaviour of the actual system, can provide useful information for design, control and decision making.

In the case of mobile robots operating on unstructured terrain and specifically in interaction with soft soil, it is important to have control on some design and control parameters of the vehicle to make it adaptable to various terrain surfaces. In reconfigurable mobile robots the position of the centre of mass of the vehicle can be changed; this results in different normal force distributions under the wheels. Also, the actuation torque and the way in which it is distributed between the wheels affect the traction force under each wheel. These parameters can be effectively used to improve the mobility of the vehicle for different maneuvers and on a range of terrain surfaces. As stated earlier, a key idea is that, often, the essential point is to have a good approximation on the variations of some performance indicators as a result of parameter changes. The detailed modeling of the vehicle-terrain interaction may not be able to provide high fidelity estimation of forces involved in the interaction. The models would be even less accurate when exact information on terrain properties is not available. Furthermore, these models, due to their complexity, do not provide a good insight on how the variations on the system parameter can influence the reaction forces. Therefore, an alternative model for the purpose of analysis and performance evaluation should be employed.

The objective of this work is to characterize the terrain reaction forces as a function of the states and parameters of the vehicle. This can be possible with the assumption of rolling at each wheel. In this case, the dynamics of the vehicle can be considered by replacing the applied forces from the terrain with constraint forces associated with position and velocity level constraints. Therefore, the generalized constraint forces can be computed as a function of states and parameters of the system. The constraint forces indicate the required terrain reaction forces, both in normal and tangential directions, to maintain the desired operating condition of no penetration and pure rolling, respectively. This allows one to perform a parametric study that can provide useful information on feasible means to achieve the desired operating conditions. This will implicitly result in a decreased level of violation of these constraints in the real system, which is desirable for improving the mobility of the system. This can lead to different levels of mobility improvements in the overall system, depending on the terrain properties. The proposed model may also be used in an analysis toolbox, running in parallel with a full simulation of the system which uses regular terramechanics models to capture the vehicle-terrain interaction. The tool can provide information on the performance of the system and suggest parameter variations to improve the mobility, while in operation. Consider a situation that the robot is operating on nonhomogeneous terrain and at a

certain instant of motion larger than normal slippage and sinkage are detected at one or more wheels. This would result in mobility reduction, or in an extreme case the entrapment of the robot. In this situation the analysis toolbox must introduce the best possible solution to improve the situation before it results in failure.

The proposed hypothesis is applied to a planar model of the robot shown in Figure 1, traveling on an irregular soft soil terrain. The ratio between the actuation torque applied to rear wheel and front wheel is $\alpha = \tau_2/\tau_1$, which serves as a parameter. The influence of this parameter on the terrain reaction forces in the normal, F_N, and tangential, F_T, directions is studied. First, a detailed model of wheel-soil interaction [1] together with the multibody model of the vehicle is used to compute the terrain reaction forces for different values of α. Next, the assumptions of rolling and no penetration of the wheels are imposed, and the corresponding constraint forces replace the reaction forces computed in the previous stage. The constraint forces, in this case, can be expressed in closed form as functions of the vehicle states and parameters, as well as of the control parameter α. This makes it possible to identify the influential parameters of the system, and their effects on the system behaviour. The results illustrated in Figure 1 show that the change in tangential forces as a result of a change in parameter α share a similar trend for both models. In this figure, λ_1 and λ_2 represent the constraint forces associated with the rolling condition at the front and rear wheels, respectively. The normal force variations were negligible in both models and are not illustrated. Therefore, in this case, the model with assumption of idealized contact can serve as a tool for qualitative prediction of the actual system behaviour, for the purpose of analysis and performance evaluation. The model used can be adapted to different rover geometries in a relatively easy way. Also, for 3-D models of rovers, the same approach can be used with multibody software, incorporating sensitivity analysis to compute the change of the performance indicators as a result of variations in system parameters.



(a) (b)

Figure 1: (a) 2-D model of the vehicle on irregular terrain (b) Traction force vs. actuation torque ratio obtained by the model with ideal contact (plain lines) and terramechanics equations (lines with markers).

References

[1] Wong, J.Y.: Theory of Ground Vehicles, 4th ed. John Wiley and Sons, Hoboken, New Jersey (USA). 2008.