Proceedings of the ASME 2014 International Design Engineering Technical Conferences &
Computers and Information in Engineering Conference
IDETC/CIE 2014
August 17-20, 2014, Buffalo, New York, USA

DETC2014-35483

OBSERVATIVE MODELS FOR DESIGN AND OPERATION OF WHEELED ROBOTS

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ABSTRACT

Increasing mobility is generally a primary objective for the design and operation of wheeled robots. This goal becomes especially challenging when these vehicles operate on soft terrain and unstructured environments. In this case, the analysis, design and operation planning of such robots are often based on predictive dynamic simulations, where the multibody model of the vehicle is combined with terramechanics relations for the representation of the wheel-ground interaction. There are, however, limitations in terramechanics models that prevent their use in parametric analysis and simulation studies.

An alternative approach to the problem can be based on the development of models that are primarily intended to represent how parameter changes in the robot design can influence performance. These models allow for the definition of performance indicators, which gives information about the behavior of the system. We will refer to these as observative models. In this work, the performance of a rover prototype was evaluated using indicators obtained with observative models. The ability of these indicators to characterize the behavior of a rover was assessed with a series of simulations and experiments. The indicators defined using observative models succeeded to capture the changes in rover performance due to variations in the system parameters. Results showed that the proposed models can provide a useful tool for the design and operation of wheeled robots operating on structured or unstructured terrain.

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OBSERVATIVE MODELS FOR ANALYSIS

The representation of wheel-terrain interaction is a key element in the study of the mobility of wheeled robots on soft terrain. A common approach is using terramechanics relations [1] to obtain the terrain reaction forces as a function of the state of the robot. The use of terramechanics, however, is limited by the high sensitivity of the obtained forces to variations in the parameters that characterize the terrain properties. Moreover, these relations were developed to represent the steady state behavior of vehicles traveling on soft terrain, and their use in the representation of dynamic operation conditions gives rise to additional complexities.

On the other hand, an alternative point of view for the analysis of rovers on soft soil can also be developed. This relates to the definition of conditions that contribute to the increase of rover mobility, and the reformulation of the dynamics model with the appropriate selection of base variables to reflect how parametric changes in the system would affect the desired optimum conditions [2]. These models will be referred to as *observative*. According to this approach, the detailed constitutive modeling of the soil is replaced by the formulation of the appropriate conditions for mobility improvement and defining performance indicators based on those. This approach has been used to develop the research started in [2], expanding its conclusions and building a proper theoretical background.

Several interpretations for rover mobility have been discussed in the literature [3]. In the case of rovers moving along a straight line on unstructured terrain, maximum mobility is obtained when the wheel slip is zero. This maximum mobility operation can be seen as the natural motion of the system provided that the conditions at the wheel-terrain interface make this possible. The reactions at the contact interfaces are developed forces. Only as much reaction force as required to provide enough traction will be generated in each maneuver.

If the configuration of the rover is characterized with a set of n generalized coordinates $\mathbf{q}$, then it is possible to define the desired operation condition of the rover via kinematic specifications. Then the constraint forces associated with the kinematic specifications will become the primary variables and represent the ground reactions necessary to maintain the maximum mobility condition. The constraint reactions can be considered as a set of performance indicators to characterize the effect of changes in rover parameters on the contact interface behavior and mobility.

CASE STUDY AND RESULTS

The application of the two introduced approaches is illustrated in the analysis of a 2-D model of a rover prototype with five degrees of freedom (Fig. 1).

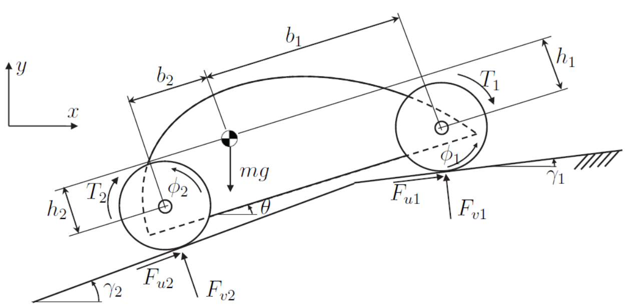

FIGURE 1. A 5 D.O.F, 2-D MODEL OF A PLANETARY ROVER ON IRREGULAR TERRAIN

The motion of the system on flat terrain was first considered using terramechanics relations to model the wheel-terrain interaction. The predicted ground reaction forces were compared to those obtained with an observative model of the rover in which kinematic specifications were used to impose no-slip and no-penetration conditions at the wheel-terrain contact points. Results showed that this observative model is able to capture the effect of changes in rover parameters on the overall behavior of the system.

Figure 2 illustrates the effect of changing the distribution of the total applied torque between the wheels on the total traction produced. The front and rear torques, T_1 and T_2 are related via constant α so that $T_2 = \alpha T_1$. A modification of α results in a change on the net tangential force the wheels develop. As shown

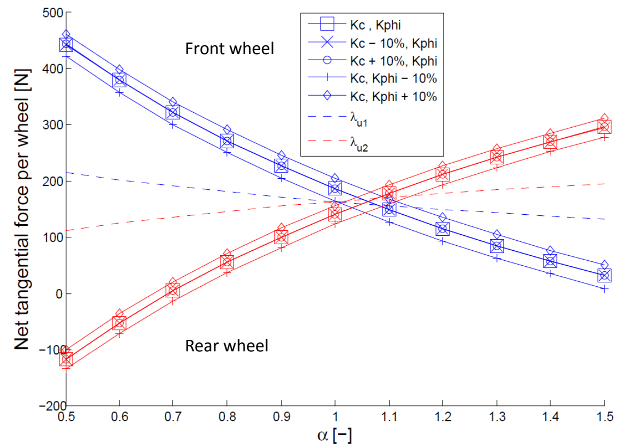

FIGURE 2. EFFECT OF TORQUE DISTRIBUTION PARAMETER α ON THE NET TANGENTIAL FORCE OBTAINED WITH THE PREDICTIVE MODEL FOR DIFFERENT SOIL PARAMETERS (SOLID LINES) AND THE OBSERVATIVE MODEL (DASHED LINES)

in the plot, the reactions provided by the use of the observative model follow the same trend as those obtained with terramechanics relations, regardless of variations in the parameters that characterize the soil properties.

Observative models can be used for the definition of meaningful performance indicators for the design and operation of planetary rovers. They allow for capturing the effect of changes in system parameters on the dynamics of the system without the need for detailed modeling of the constitution of the soil for wheel-terrain interaction.

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