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Multibody simulation of planetary rover mobility in condition of uncertain soft terrain

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Abstract

Mobility analysis of wheeled rovers plays a fundamental role in planetary exploration. In particular, the study of the rover behavior on soft terrain has got high priority. A famous, but unfortunate, example of possible consequences when driving on soft soil is connected with the NASA Mars rover Spirit that after years of successful operation got stuck on a region of poorly consolidated soil on the Mars' surface. Thus, the analysis and prediction of the rover dynamics on soft terrain is a prerequisite for successful missions. In this context, multibody analyses may greatly support the engineering design process [Krenn and Gibbesch, 2011]. Computer simulations may not only significantly reduce design costs by virtual prototyping but they can also predict the system behavior under conditions in the space often times difficult or impossible to reproduce on the earth. Nonetheless, deterministic outcomes from computer simulations do not feature the uncertainty affecting any physical framework. Considering that in space missions systems have to operate within an environment sometimes largely unknown, it turns out that embedding numerical analyses with stochastic methods can be highly beneficial. This work presents results from applying non-deterministic methods to the mobility analysis of a planetary rover under condition of uncertain terrain properties. The terrain uncertainty is initially quantified by repetitive measurements of the soil by a dedicated device and assumed to be similar to that experienced by the rover while driving. Thus, the variability of the soil properties can be propagated through the multibody model so to assess the uncertainty of the rover position when traveling a specified path. In order to check the predictive capabilities of the analysis an experiment with the rover driving a curved path on a 10° tilted plane is performed. During the experiment the wheel velocities and steering angles are recorded, which serve as input signals for computer simulations. Afterwards, uncertainty analyses are conducted. Figures 1(a) and 1(b) show a picture taken during the experimental program and a snapshot of the multibody rover simulation, respectively.

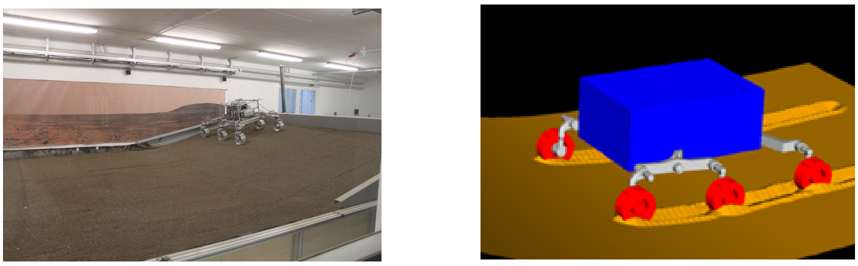
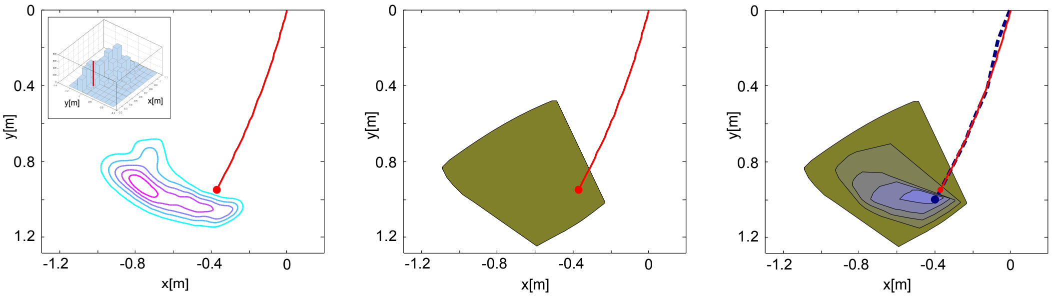

(a) (b)

Figure 1: Experimental rover test (left) and multibody computer simulation (right).

The first examined uncertainty approach is a polynomial chaos expansion. This method has already been applied to rover mobility analysis e.g. in [Ishigami et al., 2009]. However, the probabilistic representation obtained through polynomial chaos does not seem to be adequate to the existing kind of uncertainty. Indeed, this latter can be considered as a combination of aleatory and epistemic uncertainty. In order to improve the uncertainty representation, interval and fuzzy analyses are also carried out. In this case the polynomial chaos analytic function, created for probabilistic analysis, can be used as a surrogate model for fast uncertainty propagation. The obtained results from probabilistic, interval and fuzzy analyses are presented in Figures 2(a), 2(b) and 2(c), respectively. The contour plot in Figure 2(a) includes many information about the expected rover position, but unfortunately, this information can be wrong or misleading due to improper modeling of the soil parameter distributions which is impossible to assess before rover experiments. Conversely, non-probabilistic outcomes contain less but fairer outcomes. Moreover, a fuzzy description is more informative than an interval analysis thanks to additional subjective knowledge introduced by the membership function. Future work will aim to employ a Bayesian probabilistic framework for predictive rover position [Gallina et al., 2014], which is expected to overcome pitfalls of a frequentist interpretation of probability.



(a)

(b)

(c)

Figure 2: Rover position uncertainty obtained by probabilistic polynomial chaos (left), interval analysis (center) and fuzzy arithmetic (right). The blue dashed line denotes the predicted path for the assumed soil parameters crisp value (best matching), The red line denotes the experimental path traveled by the rover.

References

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