Performance Optimization and Optimal Design of Six Wheeled Rover for Uneven Hard Terrain

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by

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ABSTRACT

Numerous scientific missions over the past few decades were sent to Moon, and planets for studying and understanding the unknown aspects of our solar system. Orbiting vehicles, landers, and exploration vehicles were used for those scientific missions. Wheeled mobile robots or rovers are a class of mobile robots, used as exploration vehicles for surface exploration. Rocker-bogie suspension system is so far the most used for these exploration missions. These robotic vehicles need to negotiate rough terrain through out their life spans. Their locomotion performance is one of the critical factors, which decides the success of the mission.

A detailed survey of literature indicated that significant progress has been made in performance optimization and optimal design of rocker-bogie suspension rovers. The most popular performance parameter is coefficient of friction needed for moving without slipping. We identified two aspects of the problem formulation which appeared possible to improve. One is the characterization of solution as one with equal contact force ratios for the three wheels, which we felt is not necessary for a minimax problem with non-linear functions. The other is the implied assumption in some of the formulations that the wheel torques have to be in the same direction. So we took up improved formulations for both optimal performance and optimal design as our major goal. We consider structured terrain like large steps, and stair cases.

For optimizing performance of a given rover, we were able to propose a smooth problem formulation which does not have the two lacunae mentioned above. As our formulation is smooth, we were able to use a state of the art gradient based non-linear programming numerical solver to obtain solutions. Some of these solutions clearly demonstrate that equal contact force ratio is not a necessary and in some cases, not even a sufficient condition for minimum. They also showed that all solutions need not have wheel torques in the same direction.

Our detailed understanding of the nature of solutions led to the proposal of two analytical, non-iterative algorithms, which we show to be as effective as the powerful numerical solver in finding global optima, and much faster, and is likely to be much easier to implement in an onboard controller.

We proposed the use of an onboard manipulator to shift centre of mass, to further improve performance. We formulated this also as a smooth optimization problem which can be easily solved using the NLP solver. We then briefly address the cases where the coefficient of friction between the wheels and ground are (a) known on one patch on the ground, and (b) fully known everywhere.

The next major problem addressed is that of optimizing the design of the rover itself, considering required friction coefficient as the objective function. We considered terrains of (a) single large step, (b) three large steps, (c) staircase, and (d) a combination of (b) and (c). We also considered rovers without and with manipulator for shifting centre of mass. We were able to formulate cases (a) and (b) as smooth optimization problems and obtain solutions which we show to be at least local minima using KKT conditions. For cases (c) and (d) we could not obtain smooth formulation. However, we were able to significantly reduce the problem size and obtain good solutions using genetic algorithm.

Our work has thrown up very effective mathematical formulations for performance optimization and optimal design of rocker-bogie suspension rovers. At the end, we suggest some important directions to pursue in future.