Improved Traversal for Planetary Rovers through Forward Acquisition of Terrain Trafficability*

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Abstract— **Current operations of planetary rovers, especially the planning and execution of traverse operations, rely on human analysis and estimation of non-geometric hazards based on images captured by the rover. Despite the use of advanced path planning algorithms capable of avoiding obstacles, this greatly limits daily traverse distances. This paper presents a system capable of safe traversal beyond the range of the sensors through forward sensing of terrain trafficability, resulting in improved traversal speeds.**

I. INTRODUCTION

The past decades have seen a number of robotic missions to the Martian surface. While these missions have been extremely successful in terms of scientific data gathered, as well as technologies and capabilities demonstrated, the rovers have faced significant difficulty traversing the Martian surface. The most notable example of this is the MER Spirit which was immobilized when one of its wheels got trapped in subsurface sand.

To reduce the risk of failure, especially immobilization, current concepts for planetary rover operations rely heavily on human involvement and simulation of rover operations. With regards to traverse operations this includes building up a 3D environment of the current surroundings of the rover based on received imagery, identification of hazards including manual identification of regions with suspected subsurface hazards or high slip, and then planning and validation of paths. While suitable for reducing risk by involving experts for scene and terrain analysis, such operations methodologies limit the distance that can be safely traversed each sol to what is in visible range.

Continued interest in planetary exploration and the success of recent rovers has led to the planning of several future missions to Mars for the next decade. As the expected scientific return from these missions grow, so do the required capabilities and need for autonomous operations that do not require regular human involvement. One such mission, the Mars Sample Return Mission, would require the rover to traverse a large distance (up to 10km) from its landing site to a cached sample, and return with the sample to the landing site within a year. Allowing sufficient time for other required operations and contingencies, this results in a required daily traversal of approximately 170m – significantly beyond the capabilities of current operations.

This paper presents a system concept enabling planetary rovers to reliably and rapidly traversal of large distances over unknown terrain in preparation for such future missions. The system is based on the forward sampling of soil and terrain characteristics, allowing the autonomous detection of hazards before the rover is at risk. This reduces the need for human intervention and manual analysis of imagery, allowing the traversal to target locations beyond the range of rover sensors.

II. SYSTEM OVERVIEW

This system focusses on forward soil characterization and trafficability assessment, a scout rover and collaborative operations between the scout and primary rover (mission rover) to achieve its goal of enabling reliable traversal beyond the limits of current capabilities.

B. *Soil Sensing System*

The Soil Sensing System has been designed to provide terrain trafficability assessments and hazard detection prior to the primary rover traversal. It comprises three categories of sensing capabilities: Remote Sensing, Scout Rover Sensing and Primary Rover Sensing. Remote sensing capabilities focus on the analysis of imagery from the primary rover cameras for the detection of rocks and other hazards. Scout rover sensing is based on a suite of four soil sensors: Scout leg-Soil Interactions, Ground Penetrating Radar, Dynamic Plate and Dynamic Cone Penetrometer. A novel design for a hybrid Dynamic Plate and Dynamic Cone Penetrometer with a common driving mechanism has been developed, thus reducing the mass of the sensor suite. The sensors are deployed in a hierarchical manner, providing continuous soil characterization. Primary rover sensing is

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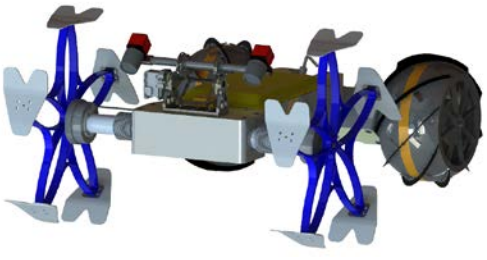

Figure 1. Rendering of the Scout Rover design.

based on an additional sensor mounted at the front of the primary rover (designed to fit the payload bay of the Bridget breadboard [1] from EADS Astrium UK). Two sensors are currently under investigation for this purpose: a wheeled bevameter and a novel 'PathBeater' sensor. The Soil Sensing System fuses data from the sensors, providing a common assessment.

B. *Scout Rover*

The scout rover is designed to host the suite of miniaturized soil sensors described above, functioning as a remote, mobile sensor for the primary rover. It is a light weight, highly mobile robotic platform able to traverse terrain that would be hazardous for the primary rover. The design is inspired by the DFKI robots ASGUARD [2] and CESAR [3], which won the 2008 ESA Lunar Challenge. It implements legged wheels at the front allowing it to traverse terrain that is scattered with rocks or on softer sand-like surfaces, while the rear wheels are fitted with inclined grousers allowing it to turn on the spot. Due to mass and size requirements imposed by expected mission parameters it is not designed to have full power autonomy - it is intended to dock with the primary rover to recharge its batteries.

C. *Software Architecture*

A modular architecture based on the G^{en}oM [4] framework has been designed to enable collaborative traversal based on the ECSS E4 level of autonomy [5] allowing "execution of goal oriented mission operations on-board". The focus of the developed design is on a Hierarchical Timeline Network [6] based planner to schedule actions of both rovers, methods for localization of the scout rover in imagery from primary rover cameras and a Guidance, Navigation and Control module performing collaborative mapping and path planning.

III. OPERATIONS CONCEPT

A. *Traversal Telecommanding*

This phase comprises the planning efforts prior to sending the traverse telecommand to the primary rover. Operators at Mission Control utilize available terrain data of the Martian surface to determine potential paths to the target location, avoiding large obstacles and geological features that are visible in orbiter data. Building on the representation of a path as an ordered set of waypoints with straight line paths in between, the collated potential paths are to be represented as a graph where each edge represents a path between two waypoints and has an associated expected cost. Such planning allows for the inclusion of contingency paths into a single traversal command.

B. *Global Path Planning*

This is the preliminary part of the rover execution of a traversal command. It uses the associated graph to identify the optimal path to the target based on expected costs. Waypoint Traversal is then iteratively executed, treating the next waypoint as the local target. At the end of each iteration expected costs are replaced with actual costs, and the updated graph is used to re-plan the global path if needed.

C. *Waypoint Traversal*

The primary rover turns towards the next waypoint, facing along the potential straight line path. A digital elevation map is built, combining data from sensors on both rovers. Remote soil sensing results, where available, will be integrated with geometric terrain characteristics and will be used to calculate a path to the waypoint (or alternatively to the end of the available elevation map if the waypoint is beyond the range of the sensors). If no direct path can be found due to detected hazards, the primary rover sensors are panned, trying to find a path that circumvents the hazard. The scout rover then moves along the planned path, using its miniaturized sensor suite to assess trafficability along the expected trajectory. If the Soil Sensing System can confidently confirm the trafficability of the path, the primary rover moves along the path at optimal velocities, otherwise it adopts a more cautious approach and proceeds along the path with its on-board soil sensor deployed. This approach is repeated until the waypoint is reached. If at any point, no further path towards the next waypoint can be identified, the corresponding edge in the graph of potential paths is replaced by a new node at the current position connected to the previous waypoint and a new global path is sought.

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