ADVANCED ROBOTIC SURFACE NAVIGATION FOR MARS EXPLORATION.

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Introduction: Fast autonomous mobility, autonomous target sampling, and terrain relative navigation promise to have a significant impact on the utility, efficiency, cost, and reliability of future robotic Mars surface missions.

The Planetary Science decadal survey calls for increased surface mobility, navigation, and autonomy of this type several times, including a need for increased rover speed over MSL and MER (p.6,340,341,342), improvement to onboard avionics to enable faster traverse mobility (p.162), automation of target approach, measurement, and sample acquisition (p.162), and mobility to address the collection of a diverse suite of samples (p.159)[1]. Improvements in mobility are not only required for Mars; fast, long range surface mobility is also called out for the Moon (p.359)[1]. Techniques that are applicable on Mars are applicable on the Moon as well.

For the past several years, the Intelligent Robotics Group (IRG) has been developing and integrating advances in autonomous navigation for planetary robotic applications. This paper will describe some research that addresses critical Mars surface exploration needs.

Fast Autonomous Mobility: In IRG's research on robotic surveying and reconnaissance, driving long distances has become an important requirement for covering wide areas and providing multiple perspectives. Field tests at Haughton Crater, Devon Island, Canada and Black Point Lava Flow, Arizona, USA have provided opportunities to develop robot capabilities and remote ground control approaches capable of covering several kilometers per day. Improvements in K10 autonomous navigation (Fig. 1) helped to increase the range and efficiency of the surface mobility under those tests. These capabilities have relied on a shift from a stop-sense-think-act cycle to a continuous driving architecture with sensing, mapping, analysis, and control happening concurrently and in parallel. [2]

Tele-operation of assets on a remote planetary surface poses a number of challenges. Time-delay, bandwidth-constraints or low gravity can make it difficult for a human operator to anticipate all potential hazards of driving the mobile platform. To mitigate this risk, IRG has developed a driver-assist system for the JSC Centaur2 robot. The autonomous evaluation of sensor data on the robot is used to provide additional information to the operator on the traversability of the terrain. These maps are sent to the remote operator as part of the robots telemetry stream. In addition, the intended route of the operator is evaluated on these terrain maps and potentially hazardous parts are flagged in the operations displays. As a final safety measure, the driver-assist system can be allowed to overwrite the operators intended drive and stop the robot instead.

Autonomous Target Sampling: Driving to scientific targets and placing instruments or tools in contact with them is a principal activity of planetary exploration. A human geologist can do this in tens of seconds, but prior to extended mission software upgrades, the MER vehicles required on the order of 3 command cycles over as many Mars days to accomplish this. In 2004 we demonstrated autonomous driving to and instrument placement on multiple targets with centimeter precision [3]. The system allowed a science team to designate multiple instrument placement targets from 10 meters away, and the rover would visit each one in turn and place a contact instrument within 1 cm of the designated point on the target. The system supported placement of a contact instrument, not a sample acquisition device, but otherwise demonstrated the capabilities required of rover autonomy to carry out terminal navigation guidance and manipulation up to the point of sample acquisition. Experiments included trials to quantify accuracy and repeatability of the system. Advances in visual tracking, navigation, stereo vision, and other core technologies since then provide a foundation for building far more capable autonomous systems.

Terrain-Relative Navigation: Surface rover operations in the context of a priori maps of a planetary body are of particular interest in traverse planning, science target selection and increasing the mapping accuracy and resolution of existing maps. Such operations require localizing the rover within the orbital map. And the coordinated use of information from orbital imaging and surface rovers provides an opportunity to fuse data for better localization accuracy. Rover localization from matched points is an attractive solution, but matching points between orbital (MRO) and ground-based (MER/MSL) images is difficult to automate given the nearly orthogonal view angles. Therefore the technique is used but with a manual step of tie point selection. Alternatively, in recent work we have used registration of wider area 3D terrain models obtained from rover and satellite imagery. This process can be automated, and can successfully provide an estimate of rover location. Figure "1" shows the ground level DEM obtained by MER in Columbia Hills in the context of the HiRISE terrain. Differences in perspective, lighting, or environmental changes that occur between orbital and in situ image capture affect the appearance of features in the terrain, but not the overall shape. Differences in camera location and viewing angle also affect 3D reconstruction accuracy, so our method uses a weighted iterative closest point method, where the relative weights of the two terrain models are determined based on the local reconstruction accuracy estimates throughout the two terrain models.

Conclusion: Advanced navigation promises to have a significant impact on the utility, efficiency, cost, and reliability of future robotic surface missions. IRG has developed fast long-range mobility, autonomous target approach, and terrain relative navigation capabilities that directly address critical near term Mars surface exploration needs.

References: [1] *Vision and Voyages for Planetary Science in the Decade 2013-2022*, Committee on the Planetary Science Decadal Survey, National Research Council, ISBN 978-0-309-22464-2, 2011. [2] H. Utz and T. Ruland. 2008. Reactive, Safe Navigation for Lunar and Planetary Robots. In *AIAA SPACE Conference Exposition*. 2008. [3] Pedersen, L., et al., “Multiple-Target Single Cycle Instrument Placement” *i-SAIRAS*, 2005.

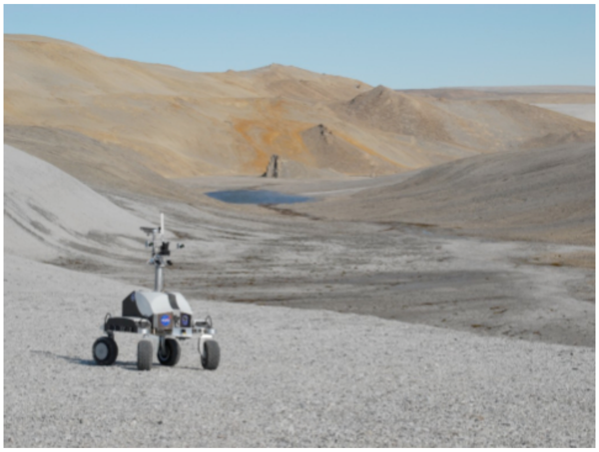

Fig. 1: K10 rover at Haughton Crater, Devon Island, Nunavut, Canada during a multi-kilometer drive with a single command uplink, from [2]

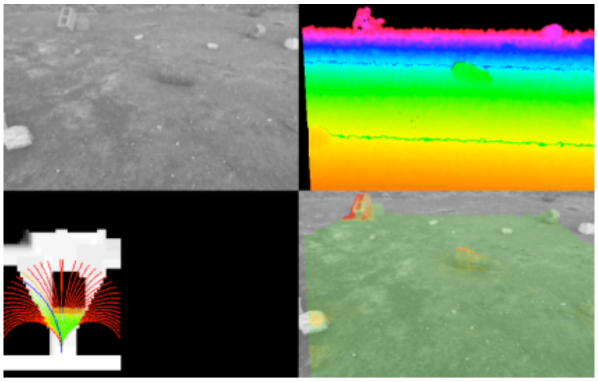

Fig. 2: High Frequency Terrain Analysis console, from [2],. Top left: one hazard camera view. Top right: reconstructed depth image. Bottom right: navigator evaluating possible paths. Bottom right: safe areas marked in green, hazards marked in red.

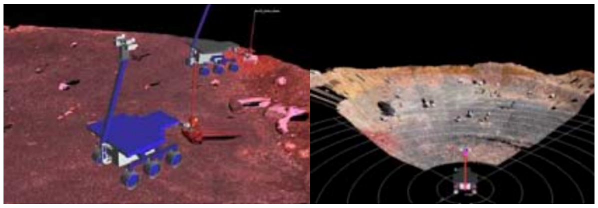

Fig. 3: Instrument Placement target designation interface allows the user to designate a sample for targeting from 10 meters away with 1cm precision, from [3]

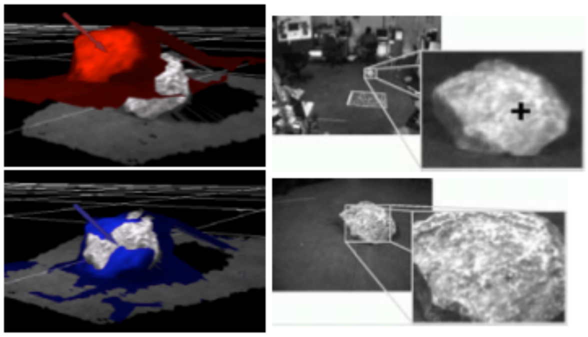

Fig. 4: Instrument placement target before and after terminal approach, showing 1cm precision, from [3]