OPPORTUNISTIC DETECTION AND MEASUREMENT OF NOVEL ROCKS

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Introduction: The Onboard Autonomous Science Investigation System (OASIS) evaluates geologic data gathered by a planetary rover [1]. This analysis is used to identify new science opportunities during a rover traverse. A planning and scheduling component enables new science measurements to be safely added to the rover current command sequence.

Recent tests have highlighted the identification of novel terrain features during a rover traverse. This capability has been recently added to the OASIS system and has been successfully demonstrated using the FIDO rover at NASA's Jet Propulsion laboratory. In addition, the system has been integrated with the MER rover mission Visual Target Tracking (VTT) capability, which enables the system to robustly track a specified target while the rover drives. By integrating this capability, the rover can be commanded to approach targets identified onboard and acquire targeted measurements both from additional viewing angles as well as from positions in close proximity to the target.

Novelty Detection: During a rover traverse, OASIS periodically acquires Navcam and Hazcam images. When an image is acquired, it is analyzed to identify rocks in the image and, for each rock, geologically salient features including albedo, size, eccentricity and angularity (shape), and orientation are determined. Each rock and its features are added to an onboard database that records the history of the traverse. Using this database, the OASIS novelty detector identifies rocks that are dissimilar from any rocks seen previously [2]. The novelty detector i) groups rocks based on feature similarity, and then ii) searches for statistical outliers from those groups. Intuitively, this has the effect of identifying and prioritizing for downlink the most novel rocks. For example, a novelty detector that utilized albedo or VIS/NIR spectral signature would identify a calcite as novel in a sea of martian basalts.

The novelty detector groups rocks based on feature similarity. To perform this grouping, rock features are treated as points in N-dimensional space and then clustered using the unsupervised k-means clustering algorithm. Once the N-dimensional points (representing rock features) have been clustered into one or more groups, statistical outliers are selected by choosing points (rocks) at least three standard deviations away from the cluster center(s). Rocks that pass this threshold test are considered novel and ranked by their distance from cluster centers (i.e. the farther away from a cluster center, the greater the degree of novelty).

We demonstrated OASIS novelty detection in the JPL Mars Yard with the FIDO rover on several traverses. In the first scenario, we turned two basalt rocks upright to represent remnants of weathered and worn dikes. The majority of the rocks situated in the yard are wider than they are tall, so the two obelisk-like upright rocks appeared to the human-eye to be novel. We set the novelty detector to operate on two rock features in our traverse database: eccentricity and orientation with respect to the ground. Navcam images were acquired every meter. We conducted several independent traverses with these settings. In every traverse, one or both of the upright rocks were detected and identified as novel by the OASIS novelty detector (Figure 1). In a second, more limited study, we examined Navcam traverse images that contained one to a few high albedo rocks amidst a field of several times as many low albedo rocks. This rock configuration was meant to simulate calcites in a sea of martian basalts. Since the JPL rovers do not have a spectrometer onboard, we relied solely on albedo as an indicator of mineral content. To that end, the novelty detector was set to operate on rock albedo from the traverse database. In every test case, the high albedo rock(s) was detected and identified as novel by the OASIS novelty detector.

Target Tracking and Sampling: This year, OASIS was shown to enable autonomous target selection for targets that require near-proximity measurements. Towards this goal, the OASIS system was integrated with the MER Visual Target Tracking (VTT) software, [3] which enables a rover to track a selected target as the rover drives and to closely approach a target location. The combined use of OASIS and VTT enables autonomous target selection and rover approach to within 1-2 meters of a target location.

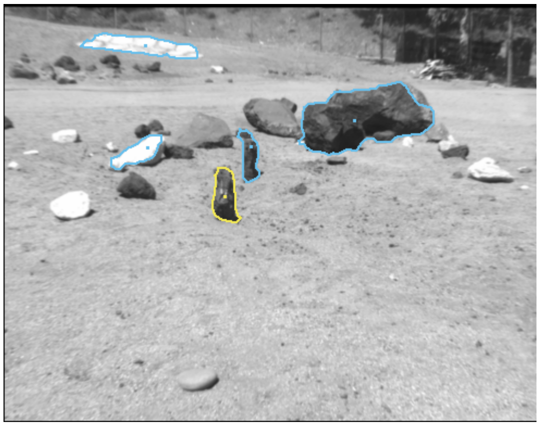

Figure 1. An example of novelty detection finding an outlier rock (labeled in yellow). The features of orientation and eccentricity were evaluated to determine novelty. This rock is representative of a geological "dike" remnant.

Currently, the typical mission operations scenario for selecting MER rover targets (remote and close-contact), is to 1) download image data that has been taken from the rover's current location, which is often the end of a drive, 2) manually identify targets on Earth using that data, and then 3) uplink new measurement commands at the next opportunity, which at best will happen on the next sol and may require several sols. This strategy is difficult to implement if the rover is driving on most sols since there is limited time to analyze the data and uplink new commands before the rover changes its location. Further, this situation becomes more complex if the measurements need to be close-contact or require the rover to be in close proximity to the target. New technology has been uploaded to the MER rovers such as VTT and automated instrument placement that can reduce the overall collection time, however targets must still typically be selected on Earth using image data that was downlinked from a previous sol.

Figure 2. As a result of novelty detection, the FIDO rover was driven to within 1m of the identified rock of interest and an additional, close-up image was taken with the FIDO panoramic cameras. FIDO then resumed its original traverse plan.

As previously discussed, OASIS enables onboard target selection based on analysis of traverse imagery. Once a target has been selected, the OASIS planning and scheduling subsystem is used to schedule new target measurements. An iterative optimization approach is used to schedule additional science activities within the rover's current command sequence. New measurements are sent to the planner in the form of science goals, where a goal represents a request for the collection of additional data and describes properties of what type of data should be collected and constraints on how the data should be collected. New measurements are only added to the current plan if they can be safely executed and no resource or other operation constrains will be violated.

Low-level robotic control capabilities, such as vision, navigation, and pose estimation are provided by the CLARAty functional layer [4]. The MER VTT algorithm was integrated with a navigation algorithm to allow the rover to navigate safely toward a feature of interest. At each step of the algorithm, the rover acquires an image with the navigation cameras pointed at where it expects the feature to be. It searches an area around this looking for a match with the target feature. When a match is found, it updates its estimate of the 3D location of the feature and updates the navigator with a revised location of where the rover should go. This process continues until the rover reaches a requested standoff distance from the target. Once the target distance is reached a close-proximity measurement of the target rock can be acquired. Figure 2 shows a panoramic image that was taken when the FIDO rover approached the target identified in Figure 1.

References: [1] Castano, et al., *Journal of Field Robotics*, 2007. [2] Castano, et al., *IEEE Aerospace*, 2008. [3] Kim, et al., *AIAA* (2005). [4] Nesnas, et al., *JARS* (2006).