NOVELTY-DRIVEN ONBOARD TARGET SELECTION IN GRAYSCALE AND COLOR MARS ROVER IMAGES. H. R. Kerner[1], K. L. Wagstaff[2], S. Lu[2], R. Francis[2], S. Kulshrestha[1]. [1]University of Maryland, College Park, MD, USA, hkerner@umd.edu, [2]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, USA.

Introduction: Mars rover operations currently consists of pre-scripted commands determined by the rover science and engineering operations teams on a day-to-day (or sol-to-sol) basis. Automated instrument targeting systems, which determine which surface features to target based on automated rather than pre-scripted decision-making, could help increase the science return from current and future exploration missions. One example of an automated targeting system is the Autonomous Exploration for Generating Increased Science (AEGIS) system, which uses the Rockster [1] algorithm to identify candidate targets and select which targets to collect follow-up observations for based on pre-defined science goals. The AEGIS system was originally developed for the Mars Exploration Rovers to identify targets for follow-up observations with the panoramic camera (Pancam) [2]. Since 2016, AEGIS has been used on the Mars Science Laboratory (MSL) rover to select targets in navigation camera (Navcam) images for follow-up observations with the ChemCam instrument. During this time, AEGIS has selected over 250 targets and has led to increased use of ChemCam by the science team overall [3].

To rank candidate targets that were identified by Rockster in Navcam images, AEGIS first computes multiple features that describe each target (namely, the target area and albedo). These features are then compared to a target "signature" specified by the science team that expresses the current science priorities in terms of the target features (e.g., a low albedo or average pixel intensity, or a large target area). The candidate targets with features closest to the target signature are ranked most highly for follow-up observation. This ranking method been effective for opportunistic onboard targeting geologic features like bedrock that are of interest for characterizing the underlying geology throughout the traverse in Gale crater. For novel geologic features that are not yet known or expected to be present, such as meteorites, follow-up observations are currently planned after the features are identified by the science team in downlinked images. To enable automatic follow-up observation of novel targets, *i.e.*, targets that differ significantly from those observed previously in the mission, we propose to equip AEGIS with a new ranking method based on novelty.

In our previous work, we showed promising results for six novelty ranking algorithms using Navcam images [4]. These algorithms assign a novelty score to each image by computing the reconstruction error when using a lower-dimensional model computed with Principal Component Analysis (PCA) or DEMUD [5], by sparsity in feature space (Isolation Forest [6]), or by deviation from either the global "background" (RX) [7] or a local window (LRX) [4]. We found that Isolation Forest and LRX ranked pre-determined novel features most highly overall for the test scenarios, closely followed by DEMUD and PCA. In this study, we evaluate these algorithms using additional scenarios where novel geology was observed in Navcam images that were not used to identify AEGIS targets operationally. In addition, we evaluate the use of color images from the mast camera (Mastcam) for identifying and ranking candidate targets for follow-up with ChemCam. Finally, we evaluate the added benefit of using color information from Mastcam for target identification and ranking compared to grayscale Navcam images by comparing novelty ranking results for the same novel targets present in both Navcam and Mastcam images.

Novel target scenarios: Our prior experiments were limited to Navcam images that were acquired as AEGIS source images in historical onboard scenarios. However, there exist scenarios where novel geologic features were observed in the larger set of Navcam images not analyzed by AEGIS. We identified several scenarios in which novel geologic features were observed in Navcam images that were not AEGIS source images. Two such scenarios are the "Lebanon" and "Littleton" meteorites [8] (observed with Navcam on sol 637) and prominent veins at Garden City [9] (observed with Navcam on sol 930). Other scenarios identified but not covered in this abstract include additional appearances of meteorites and veins as well as plate-like layering in rocks.

Coincident Mastcam image scenarios: While grayscale Navcam images provide necessary context for navigation, Mastcam images provide additional information acquired with its Bayer pattern CCD used to capture true color (RGB) observations and a filter wheel used to acquire narrowband multispectral observations in the visible to near-infrared wavelengths [10]. We hypothesize that this information can be used by onboard target selection and novelty detection algorithms to identify additional novel targets for follow-up observations with ChemCam. To evaluate the added benefit of color information in novelty-based target selection, we identified "coincident" Mastcam images: i.e., images that contained the novel targets described in the Navcam scenarios in the previous section (with similar viewing geometry and scale when possible).

Results: As in Wagstaff et al., 2020 [4], we used Rockster [1] to extract candidate targets from each source image. We then used the novelty ranking algorithms to

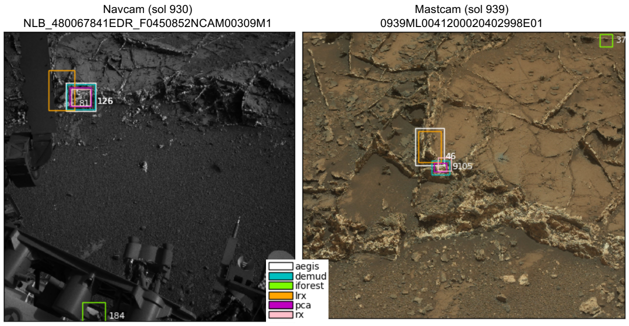

Figure 1: Garden City targets with highest novelty scores for each algorithm in coincident Navcam (left) and Mastcam (right) images. Features of interest are the veins in the bedrock.

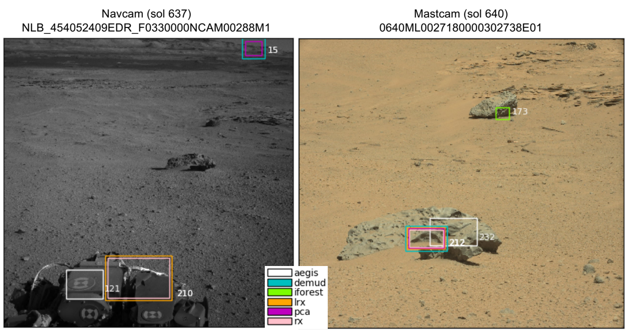

Figure 2: Targets with highest novelty scores for each algorithm in coincident Navcam (left) and Mastcam (right) images. Features of interest are the two large dark-toned meteorites ("Lebanon" and "Littleton") most prominently seen in the Mastcam image.

rank the targets from each image, represented as vectors of pixel intensities, by their novelty score. All algorithms compute the novelty score with respect to a data set of prior images defined by a sol range (except LRX, which computes the score with respect to a local window in the image). The prior sol range is typically set to be all earlier-acquired images in the data set or the last N sols prior to the test sol (e.g., N=20). We also ranked targets using a standard AEGIS ranking profile. We performed these steps for each of the Navcam and Mastcam scenarios described in the previous sections. To evaluate the ability of each algorithm to prioritize the feature(s) of interest in each scenario, we visualized the targets with the highest novelty score for each algorithm using bounding boxes.

Fig. 1 shows the target selections for coincident Navcam and Mastcam images of veins at Garden City on sols 930 (Navcam) and 939 (Mastcam). With the exception of Isolation Forest (green), the algorithms selected similar targets on the vein features of interest. The candidate targets selected by Rockster, which are the inputs used for the ranking algorithms, also appear to be similar for the targets shown in the Navcam and Mastcam images.

In Fig. 2, however, there are major differences between the Navcam and Mastcam image results. While all selections in the Mastcam image are on the meteorites, none of the selections in the Navcam image are on the meteorites. This is at least in part because Rockster did not detect the meteorites as candidate targets in the Navcam image. Even for the human eye, it is difficult to see the meteorites in the grayscale Navcam image, while they stand out clearly in the Mastcam image. This suggests that the improved contrast provided by color information in the Mastcam images may help Rockster identify additional targets of scientific interest. This could be beneficial for automatic target selection using the existing AEGIS system as well as the proposed novelty-guided system. To evaluate whether color information improves the novelty-based rankings, more experiments are needed in which Rockster detects the feature of interest as a candidate target in both the Navcam and Mastcam images. (In both scenarios, some hardware targets were selected in the Navcam images. This would not happen onboard since a hardware mask is applied in onboard scenarios.)

Conclusions and Future Work: Novelty-based ranking of targets for onboard target selection is a promising approach for increasing science return from rover instruments. We evaluated several novelty ranking algorithms for scenarios in which novel geology was observed in rover images, and we compared ranking results when color Mastcam images were used instead of grayscale Navcam images. Preliminary results show that color Mastcam images may enable detection of additional targets of scientific interest that are not detected in grayscale Navcam images (e.g., meteorites). In future work, we plan to evaluate use of image features other than pixel intensities as in [4] and conduct experiments for additional novelty scenarios, including scenarios relevant for current/ongoing MSL operations.

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