# Evaluation of Machine Learning Methodologies for Novelty-based Target Selection in Planetary Imaging Data Sets: Examples from the Mars Science Laboratory Mission

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**Abstract**

In-situ novelty-based target selection of scientifically interesting ("novel") surface features can expedite follow-up observations and new discoveries for the Mars Science Laboratory (MSL) rover and other planetary exploration missions. This study aims to identify which methods perform best for detecting novel surface features in MSL Navcam images for follow-up observations with the ChemCam instrument, as a complement to the existing Autonomous Exploration for Gathering Increased Science (AEGIS) onboard targeting system. We created a dataset of 6630 candidate targets within Navcam grayscale images acquired between sols 1343-2578 using the Rockster algorithm. These were the same target candidates considered by AEGIS, chosen to enable direct comparison to past AEGIS target selections. We employed five novelty detection methods, namely Discovery via Eigenbasis Modeling of Uninteresting Data (DEMUD), Isolation Forest, Principal Component Analysis (PCA), Reed-Xiaoli (RX) detector, and Local RX. To evaluate the algorithm selections, a member of the MSL science operations team independently identified candidate targets that represented example scenarios of novel geology that we would desire an algorithm to identify, such as layered rocks, light-toned unusual textures, and small light-toned veins. We compared these methods to selections made by AEGIS and a random baseline. Initial experiments for three scenarios showed that Local RX most frequently prioritized novel targets, followed by DEMUD and AEGIS. Our next steps in this study include evaluating input feature representations other than pixel intensities (e.g., Histogram of Oriented Gradients features), performing additional experiments to evaluate novel target prioritization performance, and selecting target candidates in Mastcam color images.

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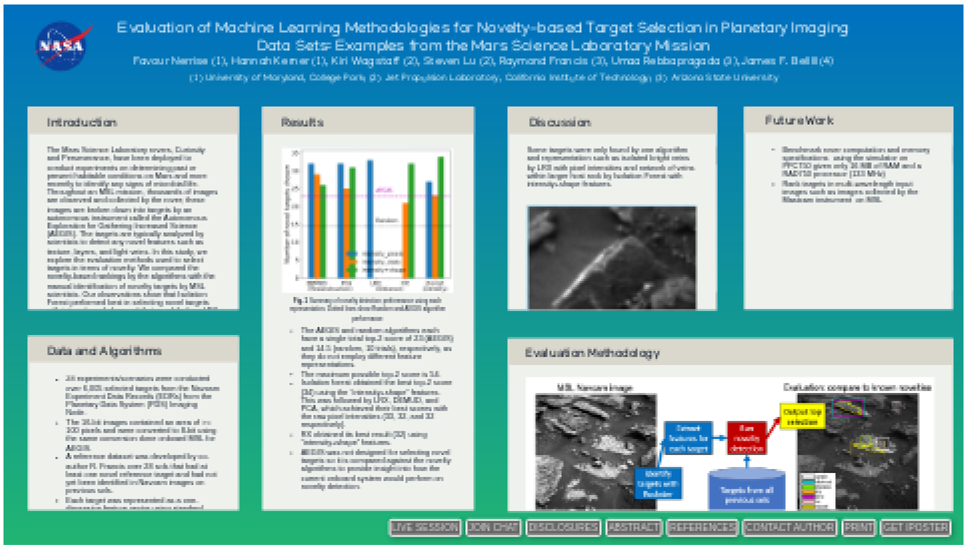


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# INTRODUCTION

The Mars Science Laboratory rovers, Curiosity and Perseverance, have been deployed to conduct experiments on determining past or present habitable conditions on Mars and more recently to identify any signs of microbial life. Throughout an MSL mission, thousands of images are observed and collected by the rover; these images are broken down into targets by an autonomous instrument called the Autonomous Exploration for Gathering Increased Science (AEGIS). The targets are typically analyzed by scientists to detect any novel features such as texture, layers, and light veins. In this study, we explore the evaluation methods used to select targets in terms of novelty. We compared the novelty-based rankings by the algorithms with the manual identification of novelty targets by MSL scientists. Our observations show that Isolation Forest performed best in selecting novel targets with intensity and shape attributes, while Local RX performed best in selecting novel targets with raw pixel features. Furthermore, all five algorithms performed higher than random selection and the sole use of AEGIS.

# DATA AND ALGORITHMS

- 28 experiments/scenarios were conducted over 6,005 selected targets from the Navcam Experiment Data Records (EDRs) from the Planetary Data System (PDS) Imaging Node.
- The 16-bit images contained an area of >= 100 pixels and were converted to 8-bit using the same conversion done onboard MSL for AEGIS.
- A reference dataset was developed by co-author R. Francis over 28 sols that had at least one novel reference target and had not yet been identified in Navcam images on previous sols.
- Each target was represented as a one-dimension feature vector using standard features—intensity_pixels, intensity_stats, and intensity+shape. The intensity_pixels attribute uses the pixel intensity values directly as features. The intensity_stats attribute computes seven statistical features to summarize the contents of the pixels within the target image. Meanwhile, the intensity+shape attribute uses nine domain-specific features computed by AEGIS for its target ranking procedure.
- The target representation (features) were broken down as follows:
  - intensity_pixels (d= 4096),
  - intensity_stats(d=7) consisting of minimum, maximum, mean, and median standard deviation, skew, and kurtosis, and
  - intensity+shape (d=9) consisting of the mean and standard deviation of pixel intensities, shape (area, perimeter, and ruggedness), ellipse-fit (eccentricity, orientation, semi-major axis length, and semi-minor axis length).
- The novelty-based ranking algorithms employed in this work are Discovery via Eigenbasis Modeling of Uninteresting Data (DEMUD), Isolation Forest, Principal Component Analysis (PCA), Reed-Xiaoli (RX) detector, and Local RX to candidate targets that represented example scenarios of novel geology. Implementations of these algorithms are discussed in further work by Kiri et al. [1].

# RESULTS

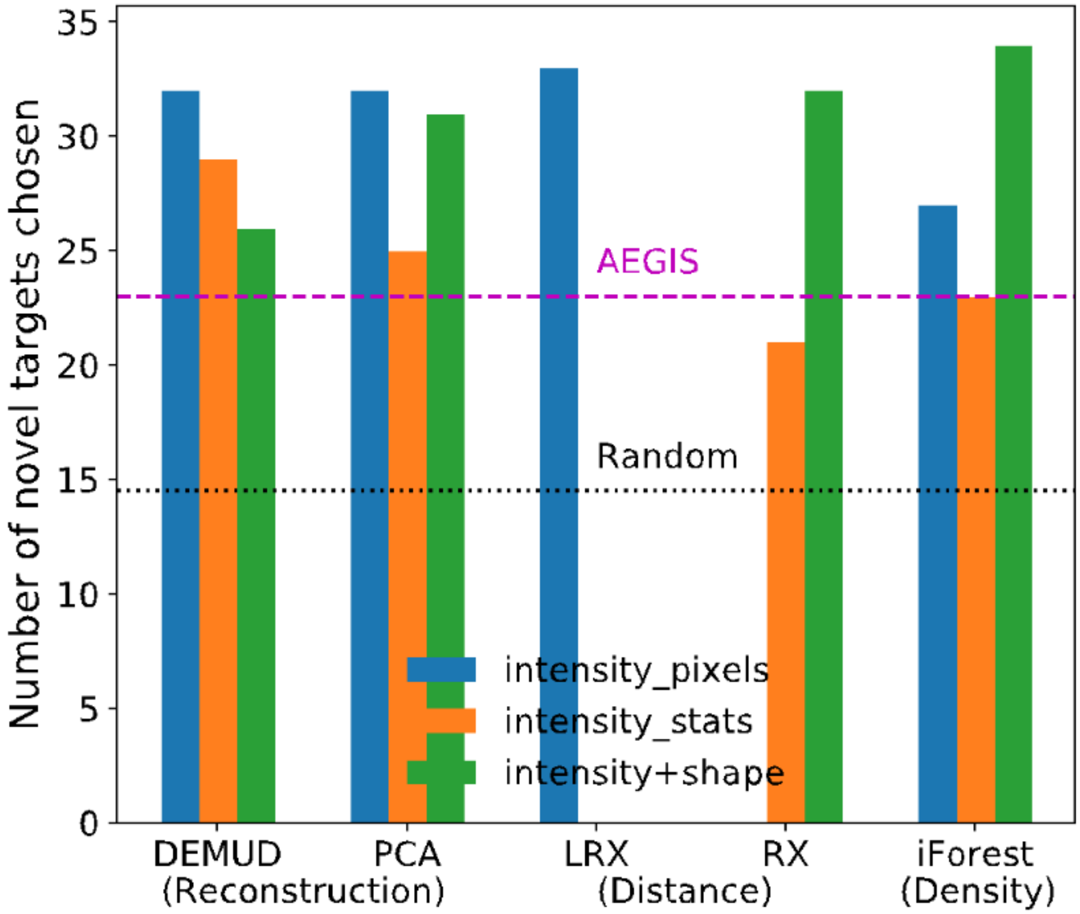


**Fig. 1** Summary of novelty detection performance using each representation. Dotted lines show Random and AEGIS algorithm performance

- The AEGIS and random algorithms each have a single total top-2 score of 23 (AEGIS) and 14.5 (random, 10 trials), respectively, as they do not employ different feature representations.
- The maximum possible top-2 score is 54.
- Isolation forest obtained the best top-2 score (34) using the "intensity+shape" features. This was followed by LRX, DEMUD, and PCA, which achieved their best scores with the raw pixel intensities (33, 32, and 32 respectively).
- RX obtained its best result (32) using "intensity+shape" features.
- AEGIS was not designed for selecting novel targets so it is compared against the novelty algorithms to provide insight into how the current onboard system would perform on novelty detection.

# DISCUSSION

Some targets were only found by one algorithm and representation such as isolated bright veins by LRX with pixel intensities and network of veins within larger host rock by Isolation Forest with intensity+shape features.

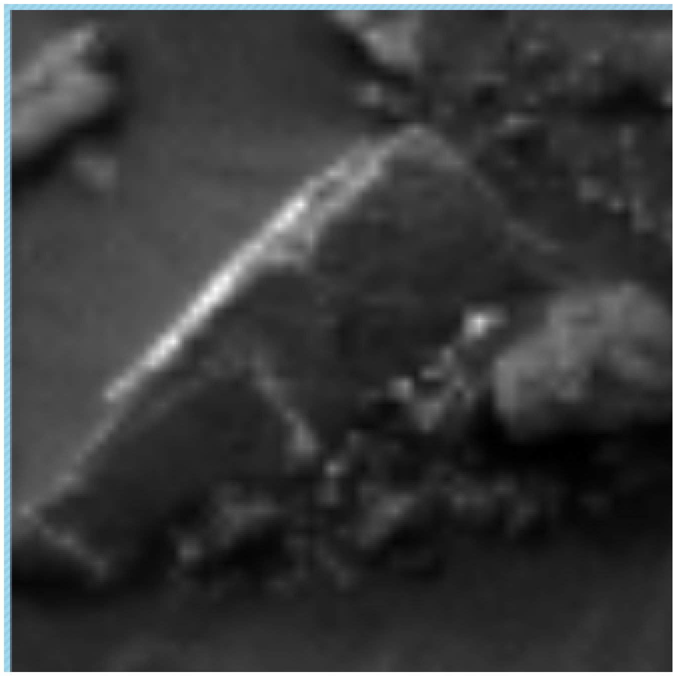

**Fig. 2** Isolated Bright Vein

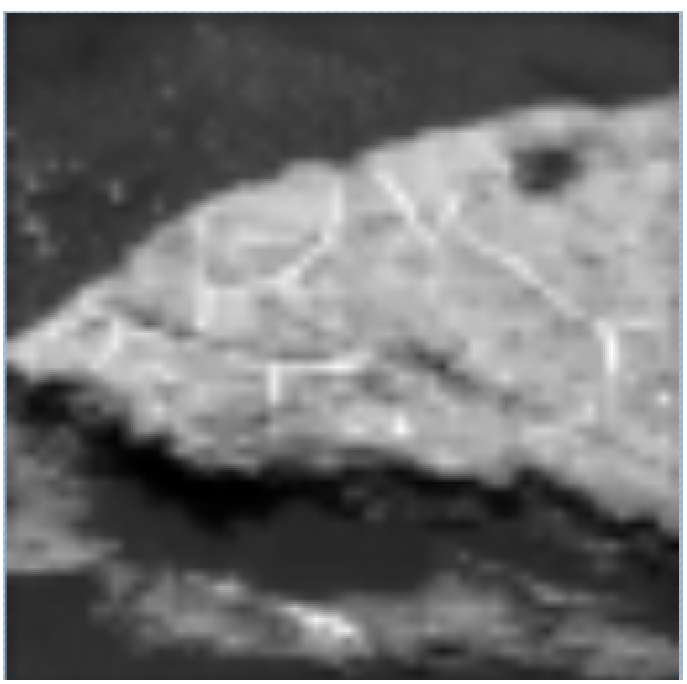

**Fig. 3** Network of veins within the larger host rock

## FUTURE WORK

- Benchmark rover computation and memory specifications using the simulator on PPC750 given only 16 MB of RAM and a RAD750 processor (133 MHz)
- Rank targets in multi-wavelength input images such as images collected by the Mastcam instrument on MSL

# EVALUATION METHODOLOGY

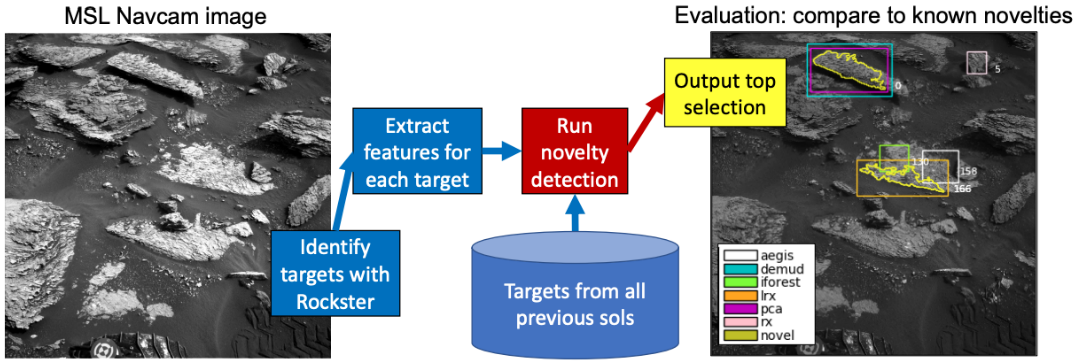


**Fig. 4** Novelty ranking process from identifying Rockster targets to evaluation target selections by novelty detection methods. Example image was collected by MSL on sol 1683.

In each scenario, the algorithms ranked all identified targets identified in one Navcam image from a given sol. The training data provided was the targets observed on previous sols. The methods then evaluated how many of the top n=2 ranked targets match manually selected novel targets. Top-2 scores were selected as the standard because the current AEGIS system is typically only able to do follow up measurements with ChemCam for 1-2 targets when it is run operationally. The total maximum score is 54.

To run the scenario, we developed bash scripts with instructions for the automated CLI processes and configuration files that contained default and specific values like rectangle/square crop or select AEGIS features for the appropriate target representation type.

# DISCLOSURES

We thank the NASA Center Innovation Fund for supporting this work. Part of this research was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

# ABSTRACT

In-situ novelty-based target selection of scientifically interesting ("novel") surface features can expedite follow-up observations and new discoveries for the Mars Science Laboratory (MSL) rover and other planetary exploration missions. This study aims to identify which methods perform best for detecting novel surface features in MSL Navcam images for follow-up observations with the ChemCam instrument, as a complement to the existing Autonomous Exploration for Gathering Increased Science (AEGIS) onboard targeting system. We created a dataset of 6630 candidate targets within Navcam grayscale images acquired between sols 1343-2578 using the Rockster algorithm. These were the same target candidates considered by AEGIS, chosen to enable direct comparison to past AEGIS target selections. We employed five novelty detection methods, namely Discovery via Eigenbasis Modeling of Uninteresting Data (DEMUD), Isolation Forest, Principal Component Analysis (PCA), Reed-Xiaoli (RX) detector, and Local RX. To evaluate the algorithm selections, a member of the MSL science operations team independently identified candidate targets that represented example scenarios of novel geology that we would desire an algorithm to identify, such as layered rocks, light-toned unusual textures, and small light-toned veins. We compared these methods to selections made by AEGIS and a random baseline. Initial experiments for three scenarios showed that Local RX most frequently prioritized novel targets, followed by DEMUD and AEGIS. Our next steps in this study include evaluating input feature representations other than pixel intensities (e.g., Histogram of Oriented Gradients features), performing additional experiments to evaluate novel target prioritization performance, and selecting target candidates in Mastcam color images.

# REFERENCES

[1] Kiri L. Wagstaff, Raymond Francis, Hannah Kerner, Steven Lu, Favour Nerrise, James F. Bell III, Gary Doran, and Umaa Rebbapragada. (2020). Novelty-driven Onboard Targeting For Mars Rovers. *International Symposium on Artificial Intelligence, Robotics, and Automation in Space.*