ROVER SCIENCE AUTONOMY IN THE FIELD: EXPLORING VIA THE HYPOTHESIS MAP

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Introduction: The Toolbox for Research and Exploration (TREX – trex.psi.edu), a NASA SSERVI node, aims to decrease operational and science risk to future missions by improving our understanding of particulate-rich surfaces. TREX studies are organized into laboratory, lunar, and small bodies studies, as well as robotic field investigation. Here, we discuss preparation for the robotic field investigation in terms of rover autonomy.

As previously described in [1,2], our goal is to understand the potential improvements in operational efficiency and science yield that can be delivered by an autonomous science rover relative to the standard rover exploration paradigm used today. The current approach to robotic exploration centers around a tight operator/robot iterative process in which a multi-disciplinary team carefully instructs the robot on every operation. Data rates impede a complete assessment of the field, so science decisions are based on expert, albeit restricted knowledge of the site.

In our proposed paradigm, we explore operational scenarios with open-ended instruction sets in which the rover is given some decision autonomy to perform science.

Rover Science Autonomy Implementation: Central to the execution of rover science autonomy is the development of the hypothesis map [3,4]. The hypothesis map represents the basis for decision-making and reporting undertaken by the robot. It contains a set of hypotheses to be explored (*e.g.*, the geologic history of a field site), and observables that allow these hypotheses to be weighted (*e.g.*, mineralogy). Given this map and its associated uncertainties, the rover calculates and executes a traverse profile that optimizes for uncertainty resolution, terrain, and resources. The rover then performs its traverse and analyses, stopping to contact the science team when it reaches predetermined waypoints or when it makes an unanticipated finding.

In our exploration strategy, the hypothesis map corresponds to an image cube where row and columns correspond to the spatial extent of the site, and each plane corresponds to a different geologic origin. The pixel values correspond to the relative probability for a geologic origin at a given location. The uncertainty in turn corresponds with the number of geologic origins with values greater than zero for that pixel. The geologic origin planes are in turn determined on the basis of the derived mineralogy for the pixel, which is in turn derived from a Tetracorder [5-7] analysis of airborne or satellite VNIR (0.35 – 2.5 μm) imaging spectrometer observations of the site. In this context, some minerals may have more than one geologic origin, or multiple minerals may be identified within a single spectrum. In scenarios like these, the pixel value for multiple geologic origin plans may be augmented, increasing the uncertainty value of that pixel.

As part of its science payload [2], the rover carries an ASD spectrometer that acquires remotely sensing spectra in the VNIR, allowing the rover to actively test newly acquired data against the hypothesis map and update the latter where the results diverge. The rover also carries other instruments that augment the science capabilities of the rover, contribute to hypothesis testing, and inform decision-making by the rover. These include an onboard gamma ray spectrometer, several contact spectrometers ranging from the UV to the thermal IR, and a portable XRD. Whereas the GRS provides an additional dimension to the exploration strategy, observations from the spectrometers could be incorporated into the Tetracorder analysis and real-time hypothesis testing with future integration of such instrumentation onto the rover.

Exploration scenarios: Three operational scenarios have been planned for comparison purposes: 1) standard fly-by-wire paradigm, 2) autonomous rover, and 3) autonomous rover with astronaut in the loop. In the latter scenario, the astronaut uses results from the scenario 2 to inform their exploration and sample collection strategies. These scenarios will be compared for operational efficiency and science yield in field exercises planned for the Oct/Nov 2020 timeframe.

References: [1] Noe Dobrea *et al.* (2018) *SSERVI Expl.. Sci. Forum.* Contrib. NESF2018-093. [2] Noe Dobrea *et al.* (2019) *SSERVI Expl. Sci. Forum.* Contrib. NESF2019-124. [3] Candela, Alberto, et al. (2017) In IEEE International Conference on Intelligent Robots and Systems (IROS). [4] Thompson, D. R., *et al.* (2011) *J. Field Robotics, July / August*. [5] Clark, R.N., *et al.* (2003) *J. Geophys. Res.* Vol. 108(E12), 5131. [6] Clark, R. N., *et al.* (2010) *J. Geophys. Res.*, 115, E10005. [7] Clark, R. N., *et al.* (2012) *Icarus* 218.