Seeing Minerals Clearly: Learning Dimension Reductions on Spectral Reflectance Libraries for Efficient In Situ Multispectral Image Acquisition and Analysis

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Abstract

Vision is critical to the exploration of an environment. Colour vision, the act of sampling light across several distinct spectral bandwidths, encodes the material boundaries and compositional context of an environment into an interpretable low-dimensional representation. The exploration of the surface of Mars by rover platforms has benefitted from multispectral vision systems, that increase the spectral extent and resolution of typical trichromatic systems, and accordingly are able to discriminate an increased number of rock and soil material classes [1]. Here we investigate the problem of choosing and combining a minimal number of colour and near-infrared spectral channels from a multispectral filter suite, to discriminate a given target material against a background, in image products captured by a multispectral imager. Solving this problem can alleviate data-volume requirements and computational and cognitive processing during a given image analysis task, two problems of relevance to ground-in-the-loop time-critical remote planetary surface exploration operations, e.g. with rover platforms or small-body rendezvous missions. This work supports preparations for the operation of the multispectral PanCam Wide-Angle Cameras of the ESA ExoMars rover [2]. PanCam will capture 12-band multispectral panoramic images of the rover surroundings that will be calibrated to units of reflectance, to provide preliminary distinctions of rock and soil classes, prior to further investigations by instruments of greater discriminative power but narrower spatial scope. Here we approach the problem by training a supervised dimension reduction method with the reflectance spectra of minerals expected at the rover landing site, *Oxia Planum*, sourced from publicly available laboratory measured spectral reflectance libraries [3]. After resampling the spectral library entries to the instrument multispectral resolution, we compute, in parallel, the optimal Fisher Ratio for each pair combination of all permutations of the spectral parameters afford by the 12-band filter set. The optimal Fisher Ratio, the inter-class separation over the intra-class variance, is computed with the dimension reduction method of Linear Discriminant Analysis, that finds the linear projection from a high-dimensional feature space to a subspace, such that the Fisher Ratio is maximised [4]. We use the resultant Fisher Ratio scores to rank the effectiveness of the spectral parameter paired combinations at separating the target from background in the projected subspace, providing an efficient method for selecting filter subsets for a

given task. Although developed in the context of ExoMars PanCam, this method is applicable to targeted imaging tasks of any multispectral imaging system, provided the task has a well-defined set of expected materials. Current and future multispectral imaging experiments set to benefit from this method include the Mastcam and Mastcam-Z instruments of the NASA Mars Science Laboratory *Curiosity* and Mars 2020 *Perseverance* rovers [5], [6], and the OROCHI instrument of the JAXA Martian Moons Exploration sample return spacecraft [7].

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