Spectral Imaging System Simulation: Preparations for the ExoMars 2020 Rover PanCam Wide Angle Cameras

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Abstract

We present the status of a spectral imaging system simulation software package, developed for preparations for quantitative analysis of images from the PanCam instrument for the ExoMars 2020 Rover. The simulation has been expanded to be adaptable to a range of camera architectures, including emulator instruments and imaging systems of past and present Mars landers and rovers. We demonstrate the application of the simulation for problems involving optimisation of image capture and processing algorithms.

1. Introduction

PanCam [1] is a mast-mounted imaging system for the ExoMars 2020 rover [2], for panoramic VNIR imaging. The objectives of PanCam relate to geological context, operations planning, and atmospheric science, achieved by means of a stereo pair of wide angle cameras (WACs), enabling 3D scene reconstructions of local morphology, with a multispectral filter suite for composition studies of the surface and atmosphere. A third camera (HRC), provides high-resolution colour images of textural detail, from a vantage point between the WAC pair. Studies relating to the material composition of scenes rely upon the reconstruction of surface reflectance and atmospheric transmission functions. However, the mapping of reflectance/transmission functions to specific material abundances is an underconstrained problem for the multispectral data acquired by PanCam. To understand the capabilities and limitations of the system, the forward transfer function between spectral features of reflectance/transmission and raw (noisy) image data is required. We describe on-going development of a simulation of the transfer function of the PanCam Wide Angle Cameras (WACs) [3], and how this can be used as a tool for predicting the ability of PanCam to capture spectral features of interest. We also demonstrate how the simulation can be used to validate and refine the algorithms and parameters involved in image acquisition and post-processing.

2. Simulating Image Capture

The transfer function of a camera system maps the spectral radiance of a scene to a digital image, according to a number of intrinsic properties of the architecture, and a small number of user-controlled and environmental parameters. Multiple subsystems are involved, including lens and filter elements, the detector substrate, and electronics. The transfer function is not constant across all pixels in the detector array, and this can be characterised by statistical distributions of intrinsic properties. Software simulation allows for these components to be modelled and these properties to be contained, such that the complete transfer function can be computed and applied to test input signals (synthetic scenes), in a time and cost efficient manner. This has been demonstrated in the literature for consumer digital cameras [e.g. 4], and in the context of remote sensing, for orbital spectral imaging systems [e.g. 5].

The input to the system is a pre-rendered, or measured, hyperspectral radiometric image cube, describing the light of a given scene passing through the aperture in radiometric units. The system is modelled in two parts. First, an optics function transforms the directional distribution of light entering the aperture into an image at the focal plane, subject to the selected filter. A detector function then transforms this irradiance image into the digital image output, subject to the exposure settings and detector temperature, and electronic components. The model is described in mathematical detail in [3]. Previously, the simulation was fixed to the PanCam architecture. Further expansions to the model now enable for arbitrary spatial and spectral resolution, for application to a range of camera systems, and Bayer Pattern transmission functions, as applicable to the High-Resolution Camera, and also to Mastcam on MSL. This development allows for the testing of the implications of the system Point Spread Function on the demosiacing of Bayer pattern raw images.

3. Operations Optimisation

3.1 Exposure Time Predictions

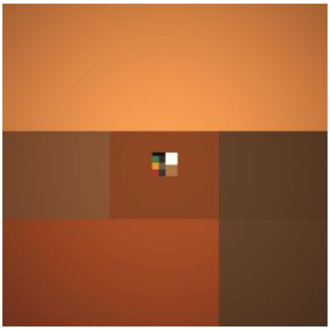

Figure 1: Simulation output from RGB channels for a synthetic test scene.

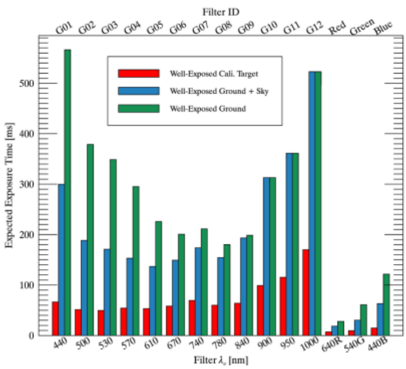

Figure 2: Predicted optimal exposure times for each filter, for the scene illustrated in figure 1.

There are many applications of the simulation. In this example, predictions are made for exposure times of all filters for an abstract synthetic Mars scene (figure 1). The scene consists of the sky spectral radiance (as measured by [6]) and several surface reflectance patches (as observed by MER Pancam [7]), and the reflectance of the PanCam Calibration Target (centre, described by [1]). The optimal exposure time is defined as the exposure that scales the brightest object of interest in the scene to 90% of the detector dynamic range. The plots in figure 2 show the changes in exposure time, depending on whether the object of interest is the calibration target, sky, or ground only.

3.2 Algorithm Optimisation

Once in operation, SNR for WAC images can be maximised by 3 key tasks: auto-exposure, for optimisation of the dynamic range used in each image; noise-removal; and calibration, against the PanCam Calibration Target and pre-flight characterisation measurements. The simulation can be used to optimise such algorithms as follows. Ideal image products for a given task are defined and synthesized from an input test scene, as a hyperspectral radiance image cube. The parameter spaces of candidate algorithms are sampled, and the input test scenes processed according to the camera system simulation and implementation of the algorithm. Resultant images from the simulation are compared to the ideal examples via a cost-function. Cost-minimisation then guides the selection of optimal algorithms and parameter combinations. Further details of this method are described in [8].

4. Summary and Conclusions

Simulation of the transfer function of spectral imaging systems allows for a variety of studies to be undertaken in preparation for upcoming missions, and also to compare expected results against existing or emulator systems. We present continued development of a software simulation, and demonstrate its application, in preparation for the ExoMars 2020 Rover mission.

Acknowledgements

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