Ultra-compact Imaging Spectrometer (UCIS) for in-situ planetary mineralogy: laboratory and field calibration
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ABSTRACT

The Ultra-Compact Imaging Spectrometer (UCIS) is a miniature telescope and spectrometer system intended for mapping terrain mineralogy over distances from 1.5 m to infinity with spatial sampling of 1.35 mrad over a 33° field, and spectral sampling of 10 nm in the 600-2500 nm range. The core of the system has been designed for operation in a Martian environment, but can also be used in a terrestrial environment when placed inside a vacuum vessel. We report the laboratory and field calibration data that include spatial and spectral calibration, and demonstrate the use of the system.

Keywords: Imaging spectroscopy, imaging spectrometer

1. INTRODUCTION

The Ultra-Compact Imaging Spectrometer aims to demonstrate an imaging spectrometer system suitable for in-situ missions, where a compact and low mass instrument can be utilized for determining mineralogy of surrounding terrain. VSWIR imaging spectroscopy has been proven to be a powerful technique in spatial mapping of mineral outcrops. Relevant examples include ESA's OMEGA instrument\(^1\) and NASA's MRO-CRISM\(^2\). Imaging spectroscopy has been implemented mainly from remote sensing instruments, but a UCIS in-situ spectrometer could map minerals on spatial scales from meters to a few millimeters and even tens of microns utilizing a microscope front end optical system.

The UCIS optical head comprises an imaging spectrometer covering the Visible to Short Wave IR range (600-2600 nm) with a small two mirror wide field telescope, a small cryocooler and peltier cooler. The basic design of UCIS has been previously published\(^3\). The optical bench assembly achieves the compact size and mass needed to develop an imaging spectrometer suitable for in-situ missions with a total instrument mass of 1.5 kg. A picture of the spectrometer optical bench and cryo-cooler is shown in Fig. 1.

Figure 1. UCIS instrument layout showing the Offner-type spectrometer, two-mirror telescope, and cryo-cooler.

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2. INSTRUMENT DESCRIPTION

The basic system specifications are given in Table 1. The detector selected for the eventual Mars system has larger pixel size than what is used in Table 1. This difference would result in a 6% increase in FOV assuming an IFOV of 2 mrad and no increase in telescope size.

Table 1. Spectrometer characteristics.

<table>
<thead>
<tr>
<th>Spectral</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sampling</td>
<td>10 nm</td>
</tr>
<tr>
<td>Spatial</td>
<td></td>
</tr>
<tr>
<td>Field of view</td>
<td>30 deg</td>
</tr>
<tr>
<td>Instantaneous FOV</td>
<td>1.35 mrad</td>
</tr>
<tr>
<td>Spatial swath</td>
<td>380 pixels</td>
</tr>
<tr>
<td>Radiometric</td>
<td></td>
</tr>
<tr>
<td>Range</td>
<td>0 – 100% R</td>
</tr>
<tr>
<td>SNR</td>
<td>&gt;300 *</td>
</tr>
<tr>
<td>Uniformity</td>
<td></td>
</tr>
<tr>
<td>Spectral cross-track</td>
<td>&gt;97% **</td>
</tr>
<tr>
<td>Spectral IFOV mixing</td>
<td>&lt; 3% ***</td>
</tr>
</tbody>
</table>

*: specified through entire spectral range, for typical hematite reflectance. **: straightness of monochromatic slit image (smile <3% of pixel width). ***: misregistration of spectrum to array row (keystone)

The UCIS sensor comprises the optical bench assembly and thermal hardware, vacuum enclosure and control electronics. The vacuum enclosure and external control electronics are designed to support testing and terrestrial field experimentation, and therefore are not analogous in the in-situ instrument implementation. The optical bench assembly and thermal hardware however are designed for use in an in-situ instrument. Fig. 2 below shows an image of the main instrument components. The focal plane array (FPA) is mounted to a six degree of freedom mount allowing the stable mounting and fine adjustment to meet the instrument uniformity requirements. The FPA mount also provides thermal isolation from the spectrometer housing and an integral cold shield that are required in order to facilitate a higher operating temperature of 270° K for the spectrometer bench and telescope, which results in lower overall thermal loads in order to meet low power requirements as needed for in-situ instruments on limited platforms. The cold shield is maintained at 230° K. The FPA is cooled using a cryocooler and the spectrometer via a peltier cooler.

![Figure 2. UCIS instrument layout showing the Offner-type spectrometer, two-mirror telescope, and cryo-cooler.](image)

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3. LABORATORY MEASUREMENTS

The key spectral and spatial response functions, measures of geometric uniformity and also variation of these metrics with telescope object focus distance. Uniformity with varying telescope focus locations is particularly important with UCIS due to its requirement of looking at objects anywhere from 3 to 1000 meters away, as would be required for a mast mounted rover in-situ instrument. Subsets of the key results from the laboratory characterization are given below, beginning with the representative spectral response functions shown in Fig. 4. The spectral response functions cover the range 600-1000 nm. The spectral response functions of Fig. 4 are normalized to unity and compiled with other similar SRF measurements throughout the field, through-field FWHM variation of less than 10% is demonstrated.

Figure 4. Spectral response functions for the middle of the field of view spanning the range 600 - 1000 nm.

Figure 5 is shows the spectral alignment and of the curvature (smile) of a monochromatic slit image. The spectral alignment is 5% of a pixel over the entire field and the smile is very small. With a small clocking adjustment net tilt can easily be removed. This confirms initial measurements made with a warm configuration published previously.

Figure 5. Scatter plot of spectral channel centroids as a function of spatial location for two isolated wavelengths (532 nm and 1550 nm).

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The spatial characteristics of UCIS were established through measurement of the cross-track and along-track spatial response functions (ARF and CRF) through field and wavelength. These are measured by scanning a subpixel slit placed at the focal plane of a collimator illuminating the instrument aperture, and oriented parallel or perpendicular to the spectrometer slit. Representative CRFs are shown in Fig. 6 for adjacent pixels and wavelengths spanning the spectral range. The FWHM are near 1.05 pixel units. The FWHM variation of the CRF with wavelength for each spatial field/focus position is less than 10%.

![Figure 6. Typical cross-track spatial response functions for adjacent pixels and several wavelengths. The vertical axis is normalized to unity. Left to right are -14 degree, 0 degree and +14 degree fields at nominal telescope focus.](image)

By measuring the centroid location of the resulting CRF (in other words, measuring the cross-track response function of the instrument) a similar measure non-uniformity can be made. The corresponding centroids are plotted against spectral channel, in Fig. 7. It can be seen that the points cluster within the ±3% band. With a small clocking adjustment net tilt can easily be removed and the total non-uniformity (or keystone) remains just below 3%.

![Figure 7. Cross-track response function centroids as a function of spectral channel for five field points spanning the instrument FOV. Linear interpolated curves are also shown.](image)
In order to demonstrate performance throughout the full telescope focus range of 3 to 1000m, the CRF centroid positions and FWHM were measured throughout the full range. The CRF centroid positions plots throughout the focus range were nearly identical. The FWHM variation of the CRF with varying telescope focus is shown in Fig. 8 with plots for each field and focus position. The FWHM are near 1.05 pixel units and stay well with spec for the three focus positions.

The telescope response was measured through focus (along scan direction). Representative ARFs are shown in Fig. 9, showing a small variation both through wavelength and (more importantly) through telescope focus position. The range of focus shown is from infinity to 1m. Nominal telescope focus is set at ~4.5m.

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4. TERRESTRIAL FIELD SETUP AND RESULTS

The UCIS terrestrial instrument was assembled and taken for testing at a suitable site for in-situ data collection, thus demonstrating instrument performance as well as the capabilities of in-situ mineralogy. The instrument optical head with its FPA and thermal electronics was integrated to a rotation stage on a tripod. In conjunction with a small instrumentation rack, this provided the ability to make terrestrial field measurements. Figure 10 shows the instrumentation rack (left) and instrument head on the rotation stage/tripod (right).

![Figure 10. UCIS optical head assembly, rotation stage and tripod.](image)

Figure 10. UCIS optical head assembly, rotation stage and tripod.

Figure 11 below shows the configuration block diagram as implemented for the terrestrial testing. End to end data processing of data was performed using the instrumentation rack computer demonstrating ease of use at future remote field locations with greater spectroscopic importance. It should be noted that the majority of these components either than the optical bench assembly and thermal hardware themselves, are required only for the terrestrial testing and are therefore not size/mass applicable to future in-situ missions.

![Figure 11. UCIS terrestrial field testing configuration block diagram.](image)

Figure 11. UCIS terrestrial field testing configuration block diagram.

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The first test was conducted at the JPL Mars Yard imaging the rock outcappings used for testing rover prototypes and other instruments. Figure 12 shows an RGB scaled image from UCIS of a 60 degree scan of the JPL Mars Yard. Several interesting mineralogical samples are located throughout the field. The resulting data is quantified in reflectance relative to a Spectralon panel that was used for flat fielding and measuring the incident solar signal.

Figure 12. 3-band color image of JPL Mars Yard.

Figure 13 shows the measured spectrum a petrified wood sample at pix # 112/330 (vert/horz) in the Fig. 12 image. The UCIS measured spectra is compared with a reference bulk spectra measured on a similar area of the sample. Figure 14 shows a UCIS measured spectra of a Ho doped Spectralon panel and the corresponding measured bulk reference spectra.

Figure 13. Comparison between measured and bulk petrified wood spectra.

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5. CONCLUSIONS

We have demonstrated the alignment and field testing of a compact spectrometer suitable for in-situ planetary mineralogy, with an optical head mass of <500 gm that includes the spectrometer, telescope, detector and mount. UCIS has been shown to meet the key spectrometer specifications desired for an in-situ instrument, including spectral/spatial uniformity throughout the large telescope focus range of 3-1000m. A complete field system was assembled, demonstrating the utility of reflectance spectroscopy and the specific UCIS spectrometer in understanding local terrain mineralogy. Future field trials are planned for Sep 2012 timeframe at locations with other mineralogical features and terrain further demonstrating the usefulness of the Ultra-Compact Imaging Spectrometer.

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