Preliminary UV/VIS Camera Calibration Results

To: Clementine Science Team
From: Brown University Spectroscopy Group
Date: February 23, 1994
Subject: UV/VIS camera basic calibration

After extended interactions with Izzy Lewis and Hye-Sook Park to understand instrument characteristics, preflight calibration data, and in-flight measurements, we have a pretty good grasp of the issues involved in the UV/VIS calibration. In order to perform our primary objective of verifying the color accuracy of the instrument, the basic calibration of the UV/VIS camera must involve accurate dark subtraction, readout correction, flat field correction, and scattered light correction. This memo principally addresses dark subtraction.

Our current understanding of the other three corrections can be summarized as follows:

a) Readout correction. A small amount of extra signal is added row by row to the image as the image is being read out at a constant rate (about 300 μs/frame). The relative magnitude of the added signal is of course dependent on the exposure time of the image. For an exposure of 5 ms a uniform field is predicted to have a top to bottom gradient of about 6%; an exposure of 10 ms would have a top to bottom gradient of about 3%. Our tests and those by Paul Lucey suggest the readout additional signal is about half that predicted. We have tested an algorithm to remove this readout signal, but need to confirm the magnitude of the added signal.

b) Flat field correction. The UV/VIS camera is pretty flat. Data are being acquired during the premapping phase to provide flat fields that can be used to correct any sensitivity deviations. TBD

c) Scattered light. Laboratory tests performed by Izzy and some inflight darks obtained at different sun angles suggest that we could be getting significant light onto the focal plane from outside the field of view. [Although less than that likely for the NIR] We have plans to estimate this from crater shadows near the poles and lunar limb scans if possible.

Dark Subtraction:

In addition to radiance from a scene (the Moon), the measured signal depends on the following parameters: gain factor (a function of gain state), integration time, temperature of the focal plane array, and an offset value (used to optimize the DN output).

The following formulation represents results from the pre-flight calibration (from Hye-Sook Park):

\[
DN(image) = gf*(C1*R*t + t*V1*exp(V2*T)) + C2g + (V3*offset)
\]

where

- \( DN(image) \) = DN value of the image (or pixel)
- \( gf \) = gain factor
- \( R \) = radiance of the scene (μW/cm²-str-μm)
- \( t \) = integration time (msec)
- \( T \) = focal plane array temperature (°C)
- \( offset \) = number of offset units
- \( C1 \) = sensitivity coefficient for an individual pixel (flatfield) (DN/[nJ/cm²-str-μm])
- \( C2g \) = dark offset (DN)
- \( V1 \) = dark noise offset (DN/msec)
- \( V2 \) = dark noise temperature dependence coefficient (1/°C)
- \( V3 \) = offset scale factor (DN/offset)

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and where

<table>
<thead>
<tr>
<th>gain state</th>
<th>gf</th>
<th>C2g</th>
<th>filter wavelength (nm)</th>
<th>C1</th>
<th>V1</th>
<th>V2</th>
<th>V3</th>
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<tbody>
<tr>
<td>1</td>
<td>1.00</td>
<td>21.7</td>
<td>415</td>
<td>1.69</td>
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<td>2</td>
<td>2.87</td>
<td>33.2</td>
<td>750</td>
<td>4.74</td>
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<td>4</td>
<td>6.34</td>
<td>58.7</td>
<td>900</td>
<td>7.05</td>
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</table>

We have analyzed several sets of dark frames obtained early in the mission (from D043033P and D047071C, as well as one Vega image set from D044022P [using the background data away from apparent stray light]). This analysis resulted in a slight reformulation of Hye-Sook's equation with the following modifications:

1) gf values were constrained to agree with the theoretical factors derived from 1000e-/bit, 350e-/bit and 150e-/bit states

2) C2g was separated into two components. One (C2g') being gain-independent, and the other (C0) being gain dependent. The value for these two were calculated through an iterative best fit to the inflight data.

The revised formulation is:

\[ \text{DN(image)} = \text{gf} \times (C1 \times R \times t) + \text{gf} \times (t \times V1 \times \exp(V2 \times T) + C0) + C2g' + (V3 \times \text{offset}) \]

where

- C2g' = gain-independent dark offset
- C0 = dark offset (gain dependent)
- V1 = 0.00366
- V2 = 0.0861
- V3 = -8.14
- T = assumed to be \(-10^\circ\text{C}\)*
- All other parameters as above

Using the dark field data sets noted above, best-fit determinations of C2g' and C0 are:

- C2g' = 15.2
- C0 = 7.6

The results of this reformulation are compared with the original in the attached figure. Misfits between the observed and reformulated calculated dark field values for integration times less than 100msec are \(\pm 1\text{DN}\) in gain states 1 and 2 (lunar integration times are expected to be <60 ms). For longer integration times the error is greater. If T=0°C is assumed, the derived formulation results in more constant misfit with integration time (Figure B).

Examples of dark values (in DN) using the reformulated calibration equation:

* A 5° variation in T results in \(\pm 0.1\text{DN}\) for exposures <40ms at gain states 1 and 2.
Gain state 4:

<table>
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<tr>
<th>Exposure (msec)</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
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<tr>
<td>7.74</td>
<td>66.0</td>
<td>57.8</td>
<td>49.7</td>
<td>41.6</td>
<td>33.4</td>
<td>25.3</td>
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<tr>
<td>13.97</td>
<td>66.0</td>
<td>57.9</td>
<td>49.8</td>
<td>41.6</td>
<td>33.5</td>
<td>25.3</td>
</tr>
<tr>
<td>61.93</td>
<td>66.5</td>
<td>58.4</td>
<td>50.3</td>
<td>42.1</td>
<td>34.0</td>
<td>25.8</td>
</tr>
</tbody>
</table>

Remaining issues:

This calibration reflects preliminary analysis of in-flight data. The majority of data used here were obtained with a 0 offset. Additional data with offsets in the 1 to 5 range are needed to further constrain the C2g' and C0 coefficients. Second, the revised calibration still results in significant errors at long integration times (i.e., greater than 150msec or so). However, most lunar data integration times will be less than 60msec, thus this issue should not significantly impact UV/VIS lunar data. Third, since the in-flight data are acquired for (nominally) dark sky, we are not guaranteed that there is no stray light in the data used in these formulations. Analysis of spatial variation in the dark indicate a very flat dark signal; deviations appear to be random and probably do not require an image frame subtraction (i.e. a constant can be subtracted instead).

Recommendations:

Use the estimated dark values from the reformulation equation, but check the values of dark being acquired each orbit. We intend to monitor these and modify the formulation if necessary.

Currently, Izzy is recommending the mapping data acquisition sequence be constrained to gain states 1 and 2 and offset values 2 (gain 1) and 3 (gain 2).