Lunar radiometric calibration on Planet Dove satellites

Arin Jumpasut, Adriana Fukuzato, Joshua Greenberg, Nicholas Wilson

August 23rd, 2017
Dove Satellite
## PlanetScope Constellation

<table>
<thead>
<tr>
<th></th>
<th>ISS Orbit</th>
<th>Sun Synchronous Orbit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Expected Lifetime</td>
<td>1 year per satellite</td>
<td>2-3 years per satellite</td>
</tr>
<tr>
<td>Mission Continuity</td>
<td>Up to 55 satellite constellation (continually replenish / upgrade satellites)</td>
<td>100-150 satellite constellation (continually replenish / upgrade satellites)</td>
</tr>
<tr>
<td>Inclination</td>
<td>52 deg</td>
<td>98 deg</td>
</tr>
<tr>
<td>Orbital Insertion Altitude</td>
<td>420km</td>
<td>505km</td>
</tr>
<tr>
<td>Ground Sampling Distance (Nadir)</td>
<td>2.7m-3.2m</td>
<td>3.2</td>
</tr>
<tr>
<td>Sensor Type</td>
<td>Bayer-masked CCD camera</td>
<td></td>
</tr>
<tr>
<td>Spectral Bands</td>
<td>Blue: 420-530nm Green: 500-590nm Red: 610-700nm NIR: 760-860nm</td>
<td></td>
</tr>
</tbody>
</table>
Image Collection

4-tap Bayer-Masked CCD Array

Bayer Mask

4-Tap Arrangement

RGB taps

Electronic readout

NIR taps
The moon shot manoeuvre

The aim of the moon shot manoeuvre is to get scenes of the moon completely within each of the four taps:
- Since each of the four taps are effectively independent
- The top two taps record the RGB bands and the bottom tap the NIR band
- This is performed when the satellite is in eclipse
The moon shot manoeuvre

- A valid scene is one that is completely within a tap as well as not having a distance too extreme from the mean position.
- Unstable scenes are scenes that are completely within a tap (and so useable) but are over a threshold from the mean position (e.g. if the satellite is transitioning between taps).
- Rejected scenes are ones that overlap a tap boundary or are otherwise unuseable.
The moon shot schedule

- During the first full available lunar cycle after commissioning, each satellite takes a full cycle of moon shots
  - This is to build up a baseline of the radiometric response of each new satellite
  - This starts from about 110 degrees phase angle waxing and continues to about 110 degrees phase angle waning
  - The different phases of the moon mean that slightly different points in the dynamic range are being measured and compared against the ROLO model
The moon shot schedule

- Every subsequent lunar cycle, moon shots are only taken at three phase angles in both the waxing and waning parts of the lunar cycle
  - This is to just provide a check that the satellite’s radiometric response is stable
  - These are taken at 10, 35 and 70 degrees phase angles in both the waxing and waning portions of the cycle
  - These can provide long term trending data on the satellites
Extraction of the moon disc

- These examples images are taken from Wikipedia’s article on lunar phase
- Attribution in clockwise order from the leftmost image:
  - By Ian Kirk from Broadstone, Dorset, UK - Here is the obligatory "I gotta a new long lens" shot!, CC BY 2.0, https://commons.wikimedia.org/w/index.php?curid=30448703
  - By Enceladus - Own work, CC0, https://commons.wikimedia.org/w/index.php?curid=14673815
Extraction of the moon disc

An outline of the per scene algorithm

- Contour detection to extract pixels at the edge of the pixel
- Fitting a function to the contour pixels (e.g. an ellipse function or a circle function)
- Testing that the extracted disc is 'sane' (e.g. within all the taps and with an area within an expected range)
Extraction of the moon disc

- An outline of the per scene algorithm
  - Contour detection to extract pixels at the edge of the pixel
  - Fitting a function to the contour pixels (e.g. an ellipse function or a circle function)
  - Testing that the extracted disc is 'sane' (e.g. within all the taps and with an area within an expected range)
Extraction of the moon disc

- An outline of the per scene algorithm
  - Contour detection to extract pixels at the edge of the pixel
  - Fitting a function to the contour pixels (e.g. an ellipse function or a circle function)
  - Testing that the extracted disc is 'sane' (e.g. within all the taps and with an area within an expected range)
Extraction of the moon disc

- An outline of the per scene algorithm
  - Contour detection to extract pixels at the edge of the pixel
  - Fitting a function to the contour pixels (e.g. an ellipse function or a circle function)
  - Testing that the extracted disc is ‘sane’ (e.g. within all the taps and with an area within an expected range)
The moon shot manoeuvre
Extraction of the moon disc

Once the moon disc has been found for each scene, the entire collect can be analysed to reject outliers:

- A linear function is fit to the area of the moon disc and outliers are rejected.
- This results in smoother measurement with edge cases being rejected.
Extraction of the moon disc

- Once the moon disc has been found for each scene, the entire collect can be analysed to reject outliers
  - A linear function is fit to the area of the moon disc and outliers are rejected
  - This results in smoother measurement with edge cases being rejected
Extraction of the moon disc

- Once the moon disc has been found for each scene, the entire collect can be analysed to reject outliers
  - A linear function is fit to the area of the moon disc and outliers are rejected
  - This results in smoother measurement with edge cases being rejected
Extraction of the moon disc

- Once the moon disc has been found for each scene, the entire collect can be analysed to reject outliers
  - A linear function is fit to the area of the moon disc and outliers are rejected
  - This results in smoother measurement with edge cases being rejected
Extraction of the moon disc

Once the moon disc has been found for each scene, the entire collect can be analysed to reject outliers:

- A linear function is fit to the area of the moon disc and outliers are rejected.
- This results in smoother measurement with edge cases being rejected.
Extraction of the moon disc

Once the moon disc has been found for each scene, the entire collect can be analysed to reject outliers:
- A linear function is fit to the area of the moon disc and outliers are rejected.
- This results in a stable **radiance** measurement with edge cases being rejected.
Collect metrics

Frame n
Collect metrics

Frame n + 1
Collect metrics

The distance between the centres of the moon disc in the two frames is the inter-frame displacement.
One final check that we do on the moon collect is to make sure that the satellite is stable when recording each tap.

- This doesn't affect which measurements we use, but is useful for diagnosis of different satellites' performance.
Implementation of the ROLO model

  - Figure 8 from the paper was re-created is to verify the implementation of the ROLO model
Results
Daily moon shot results

- This figure shows the results of an entire moon cycle of daily moon shots.
  - Each day’s collect is shown in a different colour.
  - The mean per pixel radiance is used, which is defined as:
    - the total integrated radiance over the entire moon disc
    - the number of pixels within the entire moon disc
  - There is some deviation from a linear relationship due to some influence from the phase angle that has not been corrected for yet.
Daily moon shot results

- Each moon cycle, a summary of the satellite’s performance is produced to verify that there is enough lunar data.
  - The colours are only based on the pointing stability of the satellite.
  - Due to the amount of satellites, summary graphs like this are important.
On orbit calibration vs prelaunch

- Five months after the launch of flock 3p satellites, the first on orbit update was performed
  - The results of the on orbit update vs the prelaunch calibration on lunar data can be seen
  - Currently the update is based on simultaneous crossovers with the RapidEye fleet
Monitoring of satellite health

- The lunar data is used to monitor long term trends and satellite health
  - The first satellites started this process in Q4 of 2016 and have had continuous monitoring moon shots since then
  - Moon shots have helped to diagnose and validate fixes to misaligned star cams and other hardware problems
  - This graph shows the results for a satellite’s four taps in all the bands

![Graph showing monitoring of satellite health](image)
Conclusions
Number of satellites imaging the moon
Conclusions

- There will be an archive of moon shots maintained for each satellite
  - At least one cycle of daily moon shots and a continuous history of monitoring moon shots since launch
  - If required, e.g. anomalies were detected in the monitoring moon shots, more frequent moon shots can be scheduled
  - From July 2017, there are 95 satellites taking moon shots each month (daily and monitoring)
    - And during the month of May 2017, there were 51 satellites taking daily moon shots
  - This will be useful for long term monitoring of the satellites
    - Moon shots are simpler to schedule regularly than simultaneous crossover events
- Currently this data is used for long term monitoring of the satellites
  - But eventually use this data could be used for relative calibration of the satellites
    - The effect of phase angles needs to be modelled over the full range of phase angles
  - It could also be combined with Earth facing data for absolute calibration of the satellites