Image Processing and Attitude Estimation Performance of Star Camera with Extended Bodies in the Field of View

Malak Samaan, John Christian, Steve Lockhart, and Greg Holt
JSC, Houston, TX
Outline

• Background – Attitude Sensors
• STR Flight Software: Main Functional Modules
  – Camera Control
  – Tools of Image Processing
  – Image Centroiding
• Ground Calibration for the Bore-sight Offsets and the Focal Length
  – Ground Calibration Procedure
  – Ground Calibration Results
• Master (on-board) Star Catalog
• Lost-In-Space Algorithm (LISA)
• Attitude Estimation
• End-to-End test – Stars only
• End-to-End test – Stars and Moon
• Results and Conclusion
To determine the attitude and the position of a spacecraft its orientation and location relative to some frame of reference of well known celestial body must be defined.

- **Earth Horizon Sensor**
  - Horizon sensors are infrared devices that detect the contrast of the cold of space and the warmth of the Earth

- **Sun Sensor**
  - Measure Sun angle by measuring the energy deposited in a photocell

- **Magnetometer**
  - Measure both the direction and magnitude of the magnetic field

- **Star Sensor (Star Tracker)**
  - Measure Starlight directions
STR Flight Software: Main Functional Modules – Current Status

CAMERA CONTROL
- CCD temperature
- exposure time
- # of dark frame

IMAGE PROCESSING
- Image Frame
- Pixel Response Data
- threshold DN
- max # of stars
- min star separation

LISA
- STAR PATTERN IDENTIFICATION
  - Observed Star #, RA, DEC
  - Matched Star #, RA, DEC

ATTITUDE ESTIMATION
- Attitude Matrix quaternion
- quaternion

TELEMETRY INTERFACE
- Main CPU

Star Catalog On-board-Tables
- Observed Star #, RA, DEC

Ground / On-board Calibration
Camera Control

Raw Image → Dark Subtracted Image → Calibrated Image

Dark Frames

Raw Flat Fields

Flat Dark

Master Dark

Master Flat

Diagram showing the process of camera control with images representing different stages.
Tools of Image Processing

PSF response for a typical the star.
Image Centroiding is a fundamental process in any star sensor. It’s output is the imaged star coordinates \((x, y)\).

\[
\hat{x} = x_m + \frac{\sum_{i=1}^{n} \sum_{j=1}^{n} x_{ij} I_{ij}}{\sum_{i=1}^{n} \sum_{j=1}^{n} I_{ij}} \quad \hat{y} = y_m + \frac{\sum_{i=1}^{n} \sum_{j=1}^{n} y_{ij} I_{ij}}{\sum_{i=1}^{n} \sum_{j=1}^{n} I_{ij}}
\]

\[
\hat{W}_i = \frac{1}{\sqrt{(x_i - x_o)^2 + (y_i - y_o)^2 + f^2}} \begin{pmatrix} -(x_i - x_o) \\ -(y_i - y_o) \end{pmatrix}
\]
• Star Camera Calibration is an important task in attitude determination of the spacecraft.

• Generally, star cameras are calibrated on the ground in high precision laboratories. However, any significant change in the instrument or the environment can result in this calibration being in-accurate on-orbit.

• The calibration process is mainly divided into two major parts:
  • Calibration of principal point offset \((x_o, y_o)\) and focal length\((f)\)
  • Calibration of focal plane image distortions due to all other effects (lens distortion, misalignment, detector alignment etc.)
The ideal camera parameter calibration algorithm is used to estimate the “accurate” values for the camera focal length and the focal plane offsets.

The Attitude Independent (AID) approach is used for calibration.

\[
\cos \theta_{ij} = \hat{V}_i^T \hat{V}_j = \hat{W}_i^T \hat{W}_j + \text{meas errors}
\]

\[
\hat{W}_i = \frac{1}{\sqrt{(x_i - x_o)^2 + (y_i - y_o)^2 + f^2}} \begin{pmatrix}
-(x_i - x_o) \\
-(y_i - y_o) \\
f
\end{pmatrix}
\]

\[
\hat{V}_i = \begin{pmatrix}
\cos \alpha_i \cos \delta_i \\
\sin \alpha_i \cos \delta_i \\
\sin \delta_i
\end{pmatrix}
\]

\(i=1,2,\ldots, \text{no. of imaged stars}\)
Modified from Hipparcos Star Catalog

- 12,500 guide stars for Magnitude range: -1.5 to ~ 6.4
- Number of stars within mag. threshold $M_v \leq 5.4$ is about 2870 stars
- Data: Inertial direction vectors, Visual magnitude($M_v$)

<table>
<thead>
<tr>
<th>N</th>
<th>Alpha (deg)</th>
<th>Delta (deg)</th>
<th>Magnitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>-172.1136</td>
<td>-62.9582</td>
<td>3.8000</td>
</tr>
<tr>
<td>2</td>
<td>-172.0572</td>
<td>54.5222</td>
<td>4.8000</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>l</td>
<td>113.7337</td>
<td>33.7954</td>
<td>5.4000</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2869</td>
<td>179.6033</td>
<td>51.3885</td>
<td>2.8000</td>
</tr>
<tr>
<td>2870</td>
<td>-179.4695</td>
<td>-14.6760</td>
<td>5.4000</td>
</tr>
</tbody>
</table>
Size of FOV vs Number of Stars/FOV

Average Number of Measured Stars within given FOV

Visual Magnitude

Average Number of Measured Stars

Size of FOV vs Number of Stars/FOV

OpNav FOV
The key problem is to match imaged and cataloged stars and identify the imaged stars as particular catalogued stars...

Lost-In-Space Algorithm (LISA)

Inertial Space

\[ \mathbf{v}_I = \begin{bmatrix} \cos \alpha_I \cos \delta_I \\ \sin \alpha_I \cos \delta_I \\ \sin \delta_I \end{bmatrix} \]
Matching inter-star angles for 2 Stars to within 0.001°:

=> probability of **wrong star ID** is > 0.9 !!

Matching angles for 3 Stars:

=> probability of **wrong star ID** is ~ $10^{-4}$

Matching angles for 4 or more Stars:

=> probability of **wrong star ID** is ~ $<10^{-11}$
Attitude Estimation

- Optimal Attitude Estimation
- Least squares estimation criterion
- Parameterize attitude using quaternions
- Kalman filtering to propagate and update measurements & covariance

Unit vectors towards ID ed measured Stars in body frame
Unit vectors toward ID ed stars in Inertial (catalog) frame

Attitude Estimate and Covariance

Boresight RA, Declination

To Image Processing and Star Position Measurement

\[ q = \begin{bmatrix} q_{13} \\ q_4 \end{bmatrix} \]

\[ q_{13} = \begin{bmatrix} q_1 \\ q_2 \\ q_3 \end{bmatrix} = \hat{n} \sin(\theta/2) \]

\[ q_4 = \cos(\theta/2) \]
### End-to-End test 1 – Stars only

A plot showing 22 hourly test data with points scattered across the pixel range from 0 to 2500 on both axes. The data points are marked with circles. A table follows the plot, listing each star's ID, RA, Dec, and X, Y pixel coordinates. The table includes the following details:

- Star ID
- RA (degrees)
- Dec (degrees)
- X pixel
- Y pixel

#### Star Coordinates

<table>
<thead>
<tr>
<th>Obj. Num</th>
<th>X pixel</th>
<th>Y pixel</th>
<th>Star ID</th>
<th>RA deg</th>
<th>Dec deg</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1667.3</td>
<td>1376.5</td>
<td>188</td>
<td>155.58</td>
<td>41.499</td>
</tr>
<tr>
<td>2</td>
<td>2032</td>
<td>265.9</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>708.7</td>
<td>636.2</td>
<td>405</td>
<td>163.33</td>
<td>34.216</td>
</tr>
<tr>
<td>4</td>
<td>1858.4</td>
<td>1483.2</td>
<td>271</td>
<td>154.27</td>
<td>42.915</td>
</tr>
<tr>
<td>5</td>
<td>1048.2</td>
<td>1285.3</td>
<td>627</td>
<td>156.97</td>
<td>36.708</td>
</tr>
<tr>
<td>6</td>
<td>429.8</td>
<td>1031.9</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>7</td>
<td>911.3</td>
<td>1829.2</td>
<td>900</td>
<td>151.86</td>
<td>35.245</td>
</tr>
<tr>
<td>8</td>
<td>681.1</td>
<td>1362.3</td>
<td>1155</td>
<td>156.48</td>
<td>33.796</td>
</tr>
<tr>
<td>9</td>
<td>984.9</td>
<td>224.3</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>10</td>
<td>1512.8</td>
<td>1124.4</td>
<td>1157</td>
<td>158.31</td>
<td>40.426</td>
</tr>
<tr>
<td>11</td>
<td>618.2</td>
<td>571.5</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>12</td>
<td>1853.2</td>
<td>623.6</td>
<td>1082</td>
<td>163.49</td>
<td>43.19</td>
</tr>
<tr>
<td>13</td>
<td>1503</td>
<td>488.9</td>
<td>1666</td>
<td>164.87</td>
<td>40.43</td>
</tr>
<tr>
<td>14</td>
<td>390.3</td>
<td>938.9</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>15</td>
<td>1348.4</td>
<td>451.8</td>
<td>1724</td>
<td>165.21</td>
<td>39.212</td>
</tr>
</tbody>
</table>

#### QJ2000_Cam1 and QJ2000_ST Coefficients

- **QJ2000_Cam1** = \([-0.4238, 0.0858, 0.8903, 0.1430]\)
- **QJ2000_ST** = \([-0.4219, 0.0812, 0.8894, 0.1560]\)

- qErr before align = 1.5867 deg
- qErr after align = 0.0032 deg = 11.6 arc-sec
- Accuracy Cross Boresight = 3.7 arc-sec
- Accuracy About Boresight = 11.2 arc-sec

Errors and alignment accuracy are provided with coordinates and rotation angles. The data shows a significant improvement in alignment accuracy after the alignment process.
### End-to-End test 2 – Stars only

<table>
<thead>
<tr>
<th>Obj. Num</th>
<th>X pixel</th>
<th>Y pixel</th>
<th>Star ID</th>
<th>RA deg</th>
<th>Dec deg</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>692.9</td>
<td>251.7</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>898.4</td>
<td>329</td>
<td>188</td>
<td>155.58</td>
<td>41.499</td>
</tr>
<tr>
<td>3</td>
<td>1957</td>
<td>920.4</td>
<td>405</td>
<td>163.33</td>
<td>34.216</td>
</tr>
<tr>
<td>4</td>
<td>705.5</td>
<td>1481.1</td>
<td>174</td>
<td>167.42</td>
<td>44.499</td>
</tr>
<tr>
<td>5</td>
<td>2376.8</td>
<td>1545</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>6</td>
<td>2176.3</td>
<td>1569.4</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>7</td>
<td>1526</td>
<td>327.5</td>
<td>627</td>
<td>156.97</td>
<td>36.708</td>
</tr>
<tr>
<td>8</td>
<td>828</td>
<td>1102.6</td>
<td>1082</td>
<td>163.49</td>
<td>43.19</td>
</tr>
<tr>
<td>9</td>
<td>2176</td>
<td>487.6</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>10</td>
<td>1352</td>
<td>1196.9</td>
<td>1724</td>
<td>165.21</td>
<td>39.212</td>
</tr>
<tr>
<td>11</td>
<td>1878.9</td>
<td>196.7</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>12</td>
<td>2055.8</td>
<td>971.1</td>
<td>1649</td>
<td>163.94</td>
<td>33.507</td>
</tr>
<tr>
<td>13</td>
<td>1089.7</td>
<td>556.6</td>
<td>1157</td>
<td>158.31</td>
<td>40.426</td>
</tr>
<tr>
<td>14</td>
<td>1527.9</td>
<td>1636.4</td>
<td>1205</td>
<td>169.78</td>
<td>38.186</td>
</tr>
<tr>
<td>15</td>
<td>858.9</td>
<td>1772.5</td>
<td>1594</td>
<td>170.71</td>
<td>43.483</td>
</tr>
</tbody>
</table>

\[ q_{J2000\_Cam1} = [-0.0922, -0.4168, -0.0651, 0.9020] \]
\[ q_{J2000\_ST} = [-0.0853, -0.4209, -0.0762, 0.8999] \]

qErr before align = 1.5883 deg  
qErr after align = 0.0048 deg  
Accuracy Cross Boresight = 17.35 arcsec  
Accuracy About Boresight = 4.5 arcsec  
Accuracy Cross Boresight = 15.5 arcsec
**End-to-End test 1 with Moon**

![Image of test 1 with Moon](21hr54min55sec887ms3Cam725002247.tiff)

### Table of Star Positions

<table>
<thead>
<tr>
<th>Obj. Num</th>
<th>X pixel</th>
<th>Y pixel</th>
<th>Star ID</th>
<th>RA deg</th>
<th>Dec deg</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1236.2</td>
<td>800.6</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>1370.8</td>
<td>1309.5</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>1124.6</td>
<td>66.7</td>
<td>278</td>
<td>151.83</td>
<td>16.763</td>
</tr>
<tr>
<td>4</td>
<td>2025.5</td>
<td>858.1</td>
<td>292</td>
<td>145.29</td>
<td>9.8924</td>
</tr>
<tr>
<td>5</td>
<td>1451.8</td>
<td>1155.7</td>
<td>1108</td>
<td>150.05</td>
<td>8.0443</td>
</tr>
<tr>
<td>6</td>
<td>412.1</td>
<td>1084.4</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>7</td>
<td>2185.6</td>
<td>1516.7</td>
<td>1107</td>
<td>144.61</td>
<td>4.6494</td>
</tr>
<tr>
<td>8</td>
<td>1475.4</td>
<td>701.8</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>9</td>
<td>1458.5</td>
<td>590.7</td>
<td>2182</td>
<td>149.56</td>
<td>12.445</td>
</tr>
<tr>
<td>10</td>
<td>1360.2</td>
<td>1032.7</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>11</td>
<td>1200</td>
<td>1057</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>12</td>
<td>1278.3</td>
<td>1055.8</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>13</td>
<td>2317.8</td>
<td>847.2</td>
<td>1745</td>
<td>142.99</td>
<td>9.7158</td>
</tr>
<tr>
<td>14</td>
<td>1292.2</td>
<td>1052.8</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>15</td>
<td>2294.3</td>
<td>644.8</td>
<td>1593</td>
<td>141.69</td>
<td>11.3</td>
</tr>
</tbody>
</table>

### Calculations

- \( q_{2000\_Cam2} = [-0.3031, 0.5730, 0.6364, -0.4182] \)
- \( q_{2000\_ST} = [-0.1911, 0.3845, 0.7662, -0.4781] \)

- \( q_{\text{Err before align}} = 30.0831 \text{ deg} \)
- \( q_{\text{Err after align}} = 0.0025 \text{ deg} \) = 8.86 arc-sec
- Accuracy Cross Boresight = 1.7 arc-sec
- Accuracy About Boresight = 8.3 arc-sec
**End-to-End test 2 with Moon**

\[
\text{q2000\_Cam2} = \begin{bmatrix} -0.3504 & 0.5446 & 0.6756 & -0.3525 \end{bmatrix} \\
\text{q2000\_ST} = \begin{bmatrix} -0.2537 & 0.3466 & 0.7960 & -0.4265 \end{bmatrix}
\]

\[
\text{qErr before align} = 30.0844 \text{ deg} \\
\text{qErr after align} = 0.0036 \text{ deg} = 13.0 \text{ arc-sec}
\]

Accuracy Cross Boresight = 5.6 arc-sec
Accuracy About Boresight = 12.8 arc-sec

<table>
<thead>
<tr>
<th>Obj. Num</th>
<th>X pixel</th>
<th>Y pixel</th>
<th>Star ID</th>
<th>RA deg</th>
<th>Dec deg</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1151.2</td>
<td>808.7</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>1469.8</td>
<td>1309.6</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>870.6</td>
<td>829.5</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>1196.7</td>
<td>53.3</td>
<td>278</td>
<td>151.83</td>
<td>16.763</td>
</tr>
<tr>
<td>5</td>
<td>1932.8</td>
<td>999.6</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>6</td>
<td>304.8</td>
<td>919.7</td>
<td>427</td>
<td>158.2</td>
<td>9.3066</td>
</tr>
<tr>
<td>7</td>
<td>1314</td>
<td>1184.3</td>
<td>1108</td>
<td>150.05</td>
<td>8.0443</td>
</tr>
<tr>
<td>8</td>
<td>1966.7</td>
<td>1675.7</td>
<td>1107</td>
<td>144.61</td>
<td>4.6494</td>
</tr>
<tr>
<td>9</td>
<td>969.2</td>
<td>994</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>10</td>
<td>1125</td>
<td>1076</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>11</td>
<td>1892.7</td>
<td>466.2</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>12</td>
<td>2221.2</td>
<td>1043.3</td>
<td>1745</td>
<td>142.99</td>
<td>9.7158</td>
</tr>
<tr>
<td>13</td>
<td>1426.4</td>
<td>631</td>
<td>2182</td>
<td>149.56</td>
<td>12.445</td>
</tr>
<tr>
<td>14</td>
<td>2027.7</td>
<td>1399</td>
<td>1613</td>
<td>144.3</td>
<td>6.8358</td>
</tr>
<tr>
<td>15</td>
<td>1495.4</td>
<td>1467.8</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
End-to-End test 3 with Moon

\[ q2000_{\text{OpNav2247}} = [-0.3023 \quad 0.5734 \quad 0.6369 \quad -0.4173] \]
\[ q2000_{\text{ST}} = [-0.1905 \quad 0.3847 \quad 0.7669 \quad -0.4771] \]

qErr before align = 30.0830 deg
qErr after align = 0.006 deg = 21.4 arc-sec
Accuracy Cross Boresight = 9.4 arc-sec
Accuracy About Boresight = 17.8 arc-sec

<table>
<thead>
<tr>
<th>Obj. Num</th>
<th>X pixel</th>
<th>Y pixel</th>
<th>Star ID</th>
<th>RA deg</th>
<th>Dec deg</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1215.7</td>
<td>802.7</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>1392.2</td>
<td>1308</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>1105.9</td>
<td>68.3</td>
<td>278</td>
<td>151.83</td>
<td>16.763</td>
</tr>
<tr>
<td>4</td>
<td>1432.6</td>
<td>1157.5</td>
<td>1108</td>
<td>150.05</td>
<td>8.0443</td>
</tr>
<tr>
<td>5</td>
<td>2006.4</td>
<td>860.2</td>
<td>292</td>
<td>145.29</td>
<td>9.8924</td>
</tr>
<tr>
<td>6</td>
<td>392.8</td>
<td>1085.7</td>
<td>427</td>
<td>158.2</td>
<td>9.3066</td>
</tr>
<tr>
<td>7</td>
<td>1432.6</td>
<td>965.7</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>8</td>
<td>2166.3</td>
<td>1518.8</td>
<td>1107</td>
<td>144.61</td>
<td>4.6494</td>
</tr>
<tr>
<td>9</td>
<td>1439.6</td>
<td>592.7</td>
<td>2182</td>
<td>149.56</td>
<td>12.445</td>
</tr>
<tr>
<td>10</td>
<td>2174.5</td>
<td>1235.5</td>
<td>1613</td>
<td>144.3</td>
<td>6.8358</td>
</tr>
<tr>
<td>11</td>
<td>1867.5</td>
<td>343.4</td>
<td>2431</td>
<td>145.93</td>
<td>14.022</td>
</tr>
<tr>
<td>12</td>
<td>2275.2</td>
<td>647.2</td>
<td>1593</td>
<td>142.99</td>
<td>11.3</td>
</tr>
<tr>
<td>13</td>
<td>1410.2</td>
<td>994.2</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>14</td>
<td>852.5</td>
<td>481.8</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>15</td>
<td>365.8</td>
<td>465.5</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
Percent SuccessID = 97.5610
Percent4StarsFound = 11.219
badImgCount = 0
quat. error before align (deg), Mean = 1.5898, STD = 0.0063279

quat. error after align, Mean = 22.44 arc-sec, STD = 14.17 arc-sec
Cross Bore-sight = 6.42
About Bore-sight = 19.03
Star ID – Att. Det. Results Cam1 1.0s exposure

Percent SuccessID = 98.5366
Percent4StarsFound = 7.3171
badImgCount = 0
Star ID – Att. Det. Results Cam1 1.0s exposure

quat. error before align (deg), Mean = 1.5887, STD = 0.0069389

quat. error after align, Mean = 23.23 arc-sec, STD = 15.98 arc-sec
Cross Bore-sight = 6.05
About Bore-sight = 18.17
Percent SuccessID  = 86.3415
Percent4StarsFound = 15.6098
badImgCount = 3
ImgWithMoonCount = 70
60 identified images with moon
Star ID – Att. Det. Cam2 with Moon 0.5s exposure

quaternion error after align,  
Mean = 35.96 arc-sec,  
STD = 29.03 arc-sec  
Cross Bore-sight = 5.61  
About Bore-sight = 28.78
• If the number of centroids < 4 object – no possible StarID- consider bad

22hr0min12sec762ms2Cam725002247.tiff
Star ID – Att. Det. Cam2 with Moon 1s exposure

Percent SuccessID  = 87.8537
Percent4StarsFound = 12.6829
badImgCount = 4
ImgWithMoonCount = 70
66 identified images with moon
Star ID – Att. Det. Cam2 with Moon 1s exposure

Quaternion error after align,
Mean = 31.47 arc-sec,
STD = 23.42 arc-sec
Cross Bore-sight = 6.20
About Bore-sight = 31.5
Image with stars, moon and debris (plane!)

Error = 66.8 arc-sec
Results/Statistics

• For the Star1 Camera
  – 615 total images processed (0.5 – 1.0 sec Int. time),
  – 0 bad image (no Centroiding with at least 4 stars)
  – Success star id count = 608 = 98.9 %
  – 4 Stars identified count = 60 = 9.75 %
  – Quaternion Error (with ST quat.):
    • bias = 23 arc-sec, standard deviation = 16 arc-sec
    • Cross Boresight = 6.14 arc-sec  About Boresight = 19.56 arc-sec

• For the Moon Camera
  – 615 total images processed (0.5 – 1.0 sec Int. time),
  – 40 bad image (no Centroiding with at least 4 stars)
  – Success star id count = 530 = 92.14 %
  – 4 Stars identified count = 85 = 14.85 %
  – Images with Moon count = 210 images
  – Quaternion Error (with ST quat.):
    • bias = 34 arc-sec, standard deviation = 27 arc-sec
    • Cross Boresight = 5.71 arc-sec  About Boresight = 29.16 arc-sec