Geolocation Assessment Tool and Correction Model for JPSS CrIS

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SUOMI NPP SDR Science and Validated Product Maturity Review
College Park, MD; December 18-20 2013
Content

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   • Specification, Algorithms, and Issues

2. Assessment Method
   • Using VIIRS Image Bands as a truth
   • New Collocation Method (Super Fast !!!)
   • Full Angles Assessment (All Scan Positions)
   • The results are based on angles instead of distance.

3. Correction Model
   • New Geometric Calibration Parameters based on Assessment Results

4. Summary and future work
The goal of the geometric calibration is to map CrIS line-of-sight (LOS) pointing vectors to geodetic longitude and latitude at each field of view (FOV) (9) for each scan position (30).

The purpose of geolocation assessment is to identify the error characteristics of LOS pointing vector by comparing them with the truth.

Furthermore, if the systematic errors are found, a new set of co-alignment parameters should be retrieved based on assessment results to improve the geolocation accuracy.
CrIS Scan Patterns and Specification

1.5 km (1 sigma)

Percentage of FOV size change with Scan

1.5 km (1 sigma)
Overview of Satellite Geolocation Components

CrIS (or other instrument)
- Coordinate transformation
- Interferometer
- SSM
- Sensor Isolation system
- Spacecraft

Function call to common geo:
`ellipIntersect(outPt, inst2SC, exitVec, dlat, lon, satazm, satzen, range)`

JPSS or any satellite
- COMMON GEO
  - Spacecraft
  - Orbital
  - ECI
  - ECEF(ECR)
  - Geodetic

GEOLOCATION ASSESSMENT
- GCP/Maps/Ground truth
- the other instrument measurements with enough geolocation accuracy
- Comparing the truth and CrIS Geo fields

Geolocate each FOV

ADCS
- Pos/Vel/Quaternion (RPY)
- Attitude Determination & Control System (ADCS)
- SGP4

Modified from C. Cao
CrIS Geometric Calibration Algorithm
Sensor Specific Algorithm

SDR Algorithm Process

1) LOS in IOAR coordinate = ILS parameters (3x3)
2) Convert from IOAR to SSMF coordinate
3) Compute normal to SSM mirror in SSMF (30 Scan Pos)
4) Apply SSM mirror rotation to get LOS in SSMF coordinate
5) Convert from SSMF to SSMR coordinate
6) Convert from SSMR to IAR coordinate
7) Convert from IAR to SAR coordinate
8) SAR coordinate = SBF coordinate
Geolocation Assessment Method

Method 1: 1) Retrieving land features (coast lines) from CrIS measurements; and 2) comparing then with the truth dataset

Method 2: 1) Simulating CrIS measurements from the truth measurements and 2) comparing them with accrual CrIS measurements
Unlike an imager, it is very hard to assess geolocation sub-pixel accuracy for CrIS using the land feature method because of 1) relatively large footprint size (above 14 km); 2) the gap between footprints; and 3) Uneven spatial distribution of CrIS Footprints.
Using VIIRS to simulate CrIS and then take the difference between CrIS and VIIRS, the geolocation errors immediately showed up.
Reference: Using VIIRS Geolocation
(I5 band: 375m resolution)

Table 2. VIIRS Geolocation Accuracy

<table>
<thead>
<tr>
<th>Residuals</th>
<th>First Update 23 February 2012</th>
<th>Second Update 18 April 2013</th>
</tr>
</thead>
<tbody>
<tr>
<td>Track mean</td>
<td>-24 m, -7%</td>
<td>2 m, 1%</td>
</tr>
<tr>
<td>Scan mean</td>
<td>-8 m, -2%</td>
<td>2 m, 1%</td>
</tr>
<tr>
<td>Track RMSE</td>
<td>75 m, 20%</td>
<td>70 m, 19%</td>
</tr>
<tr>
<td>Scan RMSE</td>
<td>62 m, 17%</td>
<td>60 m, 16%</td>
</tr>
</tbody>
</table>

from Wolf et al. 2013
1. Limited to scan angles less than 30 degree, especially at nadir ➔ full angles’ assessment
2. Assessments are based on distance in in-track and cross-track direction ➔ based on angles
3. Correction model ➔ a new set of co-alignment parameters
Misalignment between CrIS and VIIRS at the end of scan
Retrieved the true LOS vector

Assuming that Common Geolocation part is correct
Retrieved CrIS LOS Pointing Vector in ECR or ECEF

\[\text{[Zenith, Azimuth, Range] } \Rightarrow \text{ [East, North, Up] in local Cartesian (ENU) coordinates}\]

\[\text{D: LOS Pointing Vector}\]
\[\text{P: Satellite Position Vector}\]
\[\text{G: FOV position Vector on Earth Ellipsoid}\]

\[\text{[East, North, Up] + [Lon, Lat] } \Rightarrow \text{ [X, Y, Z] in ECEF}\]
The retrieved LOS vectors $\mathbf{D}$ can be indirectly validated by comparing two satellite position vectors: the ones saved in CrIS geolocation data and the others derived from the retrieved vector $\mathbf{G}$ and $\mathbf{D}$ ($\mathbf{P} = \mathbf{G} - \mathbf{D}$).
Build Orbital Coordinate System (OCS) in ECR or ECEF

- $P_{sat}$ and $V_{sat}$ in ECEF are saved in Geolocation dataset
- $P_{sat}$ => Z axis
- Y axis => crossp(Z, V_{sat})
- X axis => crossp(Y, Z)
We consider the linearly independent reference vectors $\vec{R}_1$ and $\vec{R}_2$. Let $\vec{r}_1, \vec{r}_2$ be the corresponding measured directions of the reference unit vectors as resolved in a body fixed frame of reference. Then they are related by the equations,

$$\vec{R}_i = A \vec{r}_i$$

(1)

for $i = 1, 2$, where $A$ is a rotation matrix (sometimes also known as a proper orthogonal matrix, i.e., $A^T A = I, \det(A) = +1$). $A$ transforms vectors in the body fixed frame into the frame of the reference vectors. Among other properties, rotational matrices preserve the length of the vector they operate on. Note that the direction cosine matrix $A$ also transforms the cross product vector, written as,

$$\vec{R}_1 \times \vec{R}_2 = A (\vec{r}_1 \times \vec{r}_2)$$

(2)

Triad proposes an estimate of the direction cosine matrix $A$ as a solution to the linear system equations given by

$$\begin{bmatrix} \vec{R}_1 : \vec{R}_2 : (\vec{R}_1 \times \vec{R}_2) \end{bmatrix} = A \begin{bmatrix} \vec{r}_1 : \vec{r}_2 : (\vec{r}_1 \times \vec{r}_2) \end{bmatrix}$$

(3)

We have $Z$ and $X$ in ECEF, corresponding to $[0, 0, 1]$ and $[1, 0, 0]$ in OCS. And then we can derive transformation matrix $A$ (ECEF $\Rightarrow$ OCS).
From OCS ➔ Spacecraft

The transformation matrix from OCS to Spacecraft coordinates

\[
T_{sc/ orb} =
\begin{bmatrix}
\cos \xi_y \cos \xi_p - \sin \xi_y \sin \xi_r \sin \xi_p & \sin \xi_y \cos \xi_p + \cos \xi_y \sin \xi_r \sin \xi_p & -\cos \xi_r \sin \xi_p \\
-\sin \xi_y \cos \xi_r & \cos \xi_y \cos \xi_r & \sin \xi_r \\
\cos \xi_y \sin \xi_p + \sin \xi_y \sin \xi_r \cos \xi_p & \sin \xi_y \sin \xi_p - \cos \xi_y \sin \xi_r \cos \xi_p & \cos \xi_r \cos \xi_p
\end{bmatrix}
\]

(Roll, Pitch, Yaw) in µrad
(34.607031 29.572295 12.285854)

0.9999999995 0.0000122869 -0.0000295723
-0.0000122859 0.9999999993 0.0000346070
0.0000295727 -0.0000346067 0.9999999990
Defining $\alpha$ and $\beta$ angles of CrIS LOS vector in Spacecraft Coordinate

$Y$: CrossTrack

$X$: InTrack

$Z$: from satellite Pointing Earth Surface

$\beta = \text{atan}(y/z)$

$\alpha = \text{atan}(x/z)$

$P$: unit vector of LOS in SBF $(x, y, z)$
α and β Angles
varying with Scan Position (FOV5)

Noted that the yaw patterns of α angles are caused by the Earth Rotation
α and β angles are step-by-step perturbed by 21 steps with an angle of 375/833/1000.0.
Flowchart for VIIRS-CrIS Geolocation

1. **VIIRS Vector in ECEF**
2. **VIIRS Geo. Field**
3. **Collocate VIIRS and CrIS**
4. **Output Collocated Results**
5. **Loop by 21x21 steps**
6. **Convert CrIS LOS vector into ECEF**
7. **Perturb α and β angles with small angles**
8. **Compute LOS Vector in S/C Frame**
9. **Compute LOS Vector in Orbit Frame**
10. **CrIS Sat_P and V in ECEF**
11. **CrIS LOS Vector in ECEF**
12. **Produce new CrIS LOS vector in SBF**
13. **CrIS Geo. Field**

Steps:
- Perturb α and β angles with small angles
- Compute LOS Vector in Orbit Frame
- Compute LOS Vector in S/C Frame
- Convert CrIS LOS vector into ECEF
- Output Collocated Results
- Loop by 21x21 steps
- Produce new CrIS LOS vector in SBF
The collocation problem is simplified as, check the angle between two vectors, [LOS_VIIRS, LOS_CrIS].
Collocating VIIRS with CrIS FOV

Histogram of VIIRS M16 in CrIS FOV

From Mark Esplin
Spectral Integration: from CrIS to VIIRS

CrIS spectrum is convolved with VIIRS SRFs for I5 band (350m spatial resolution)

\[ L_i = \frac{\int_{v_1}^{v_2} R(v)S_i(v) dv}{\int_{v_1}^{v_2} S_i(v) dv} \]
An Example

[Image of a graph showing a scatter plot with two lines and annotations for X_min and Y_min values. The graph also includes color bars for BT [K] and VIIRS [K].]
$D_{\alpha}$ with FOR index based on 15 days’ data

Mean + stdev
Fitting line
D_β with FOR index based on 15 days’ data

Mean + stdev
Fitting line

D_β

delta Beta [urad]
FOR Index
Retrieval of New Geometric Parameters

SDR Algorithm Process

1) LOS in IOAR coordinate = ILS parameters (3x3)

2) Convert from IOAR to SSMF coordinate (2 angles)

3) Compute normal to SSM mirror in SSMF (30 Scan Pos) (60 angles)

4) Apply SSM mirror rotation to get LOS in SSMF coordinate

5) Convert from SSMF to SSMR coordinate (3 angles)

6) Convert from SSMR to IAR coordinate (3 angles)

7) Convert from IAR to SAR (3 angles)

8) From SAR=> SBF coordinate (0 angels)

9) From SBF=> Spacecraft (3 angles)

Given the assessment results with 60 angles, the best strategy is to retrieve 60 scan mirror rotation angles.
Retrieval of New Geometric Parameters

- Retrieved LOS\(_{\text{s/c}}\) at each scan position on D\(_{\alpha}\) and D\(_{\beta}\)

- Step-by-step through each matrix to the coordinate SSMF:
  - LOS\(_{\text{s/c}}\) → LOS\(_{\text{SBF}}\) → LOS\(_{\text{SAR}}\) → LOS\(_{\text{IAR}}\) → LOS\(_{\text{SMR}}\) → LOS\(_{\text{SSMF}}\)

- Retrieve the normal vector \(\mathbf{n}_{\text{SSMF}}\):  
  - LOS\(_{\text{SSMF}}\) = LOS’\(_{\text{SSMF}}\) − 2*(LOS’\(_{\text{SSMF}}\) \cdot \mathbf{n}_{\text{SSMF}}) \mathbf{n}_{\text{SSMF}}

- The normal vector \(\mathbf{n}_{\text{SSMF}}\) can be used to retrieve the actual cross-track angle and actual in-track angles of Scan Mirror
Retrieved SSMF In-track Angles

 Retrieved Values

Values in EngPKT

FOR Index

In_track SSM Angle [uRad]
Retrieved SSMF Cross-track Angles

The graph shows the relationship between Xtrack SSM Angle [uRad] and Cross_track SSM Angle [uRad]. The line represents the retrieved values in EngPKT, with the label "Retrieved -EngPKT" clearly marked on the graph.
Only correct cross-track direction
Correct Both cross-track and in-track Direction
Conclusion and Future Work

• A new tool is developed to identify the error characteristics of CrIS LOS pointing vector at all scan positions.

• A correction model is developed to retrieve a new set of SSMF scan angles based on assessment results to further improve the geolocation accuracy.

• **Future work**
  – FOV5 off-axis angle sign change
  – Possible angle adjustment
Define Orbital Coordinate System (OCS)

- P_sat and V_sat in ECEF are saved in SDR
- p_sat => Z axis
- Y axis => crossp(Z, V_sat)
- X axis => crossp(Y, Z)