Image Co-Registration
For Onboard Low Latency Products

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Goals

- **Co-register** hyperspectral/multispectral bands onboard within a **few seconds**

- Proof-of-Concept using EO-1 ALI L1GST

- 9 Bands @30m resolution 16.4MB TIF Int16 ~(2231x3671)

- **Rationale:** Current EO-1 L1GST Data Product Offset Not Good for Low Latency Products
Previous Workflow

• For One EO-1 ALI L1GST Scene:
  - Find/Make [30-150] Chips from Landsat GLS2000 (Landsat Band 7-- 2.1 to 2.3 microns)
  - Subset Matching Tile(s) from EO-1 ALI Scene (EO-1 Band 8 --- 1.2 to 1.3 microns)
    ✓ Issue was whether we are detecting the same features using these bands
  - Apply Filter, Linear Stretch and Convert to Byte
  - Apply co-registration (ureg) -> Tx,Ty [,Theta,Scale] for each tile
  - Using Median RST to Determine Average Transformation
  - Apply Transformation To Band File(s)
  - Visual Assessment
Current Workflow

• Make 1 Best Chip from Best Available Landsat L8 scene from the Amazon Cloud (latest, least cloudy one) (Landsat 8 Band 7 --- 2.107 to 2.294 microns)

• Subset Matching Tile from EO-1 ALI Scene (EO-1 Band 10-- 2.08 to 2.35 microns)

• Apply co-registration (ureg) -> Tx, Ty [ do not use Theta, Scale]
  
  ➢ Ignoring theta because theta is small, would normally be a expensive transform to apply
  
  ➢ Ignoring scale because it is always one
  
  ➢ Translation is easy, only change origin in header thus is can be very fast

• Generate Automated Metrics (to assess the results of the transformation)

• Ported code to various flight testbeds
Timing Metrics

- Assumptions:
  - Only timing the coregistration portion, not acquisition of data
  - EO-1 scene (16.4 Mbytes per band) with loaded chip

- Results to subset an EO-1 tile and determine transformation parameters
  - 0.38 s (Mac OSX)
  - 3.44 s (Flight Testbed – 667MHz ARM ZC702 (1 Core))
  - 6.78 s (Flight Testbed – 1GHz TILE-Gx36 (1 Core))
  - 33.18 s (Flight Testbed – 864MHz TILEPro64 (1 Core))

- Time to Apply RST Transformation to One TIF Band (x 9 bands)
  - < 0.01s
Quantifying Registration Errors

- **Problem:** How To Automatically Quantify The Mis-registration Before and After Registration?

- Root Mean Square Error (RMSE) (Coulter & Stow 2012)
  
  - RMSE = $\sqrt{\sum_{1}^{N} ((x_1-x_2)^2 + (y_1-y_2)^2)/N)}$

  - Using Automatically Detected Top 10 Features between Chip and Matching Tile

  - **How:** using SURF (Speeded-Up Robust Features), Brute Force Matcher, and error catching using RANSAC

  - Compute RMSE on Matched Features

- Use Several Algorithms and Average Results (WORK IN PROGRESS)
Chip Determination

• Rationale:

  • Avoid Onboard Database (210GB)

  • Avoid Real-time Search for Chip(s)

  • Use Direct Retrieval of Chip if Stored Onboard or Load it With Command Load With Option to store or not
QuadKey Tiles
(similar algorithm as used by Bing/Google)

- Used to identify chip subset for the specified Landsat 8 scene and the matching EO-1 scene
- Square Tiles
- Every Target Belongs to a QuadTile
- QuadTile Easy To Find (Algorithm)
- QuadTiles have QuadKeys (aka Name)
- Quad-Neighbors Easy To Find

Example: Target: latitude, longitude [8.01, 98.56]
-> Quadkey12 Bounding box = “132221300201” [7.88, 98.44, 8.06, 98.66]
Quad-Tile Size Trade

<table>
<thead>
<tr>
<th>Hash len</th>
<th>Size km</th>
<th>Res m/px</th>
<th>GLS Pixels</th>
</tr>
</thead>
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<tr>
<td>11</td>
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<td>75.7</td>
<td>648x648</td>
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<td>9.7</td>
<td>37.85</td>
<td>324x324</td>
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<tr>
<td>13</td>
<td>4.8</td>
<td>18.9</td>
<td>162x162</td>
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</tbody>
</table>
Co-registration
Namibia Example
Flood Map Workflow

• EO-1 Scene from USGS (10 bands - \textbf{92MB compressed})
  
  ➢ Generate Water Surface Extent
  
  ➢ Apply HAND mask
  
  ➢ Apply Cloud mask
  
  ➢ Generate Final Raster
  
  ➢ Generate Compressed Topojson Vector Product (\textbf{24KB})
    
    ✓ Aka low latency product

• Display on Browser using geojson.io
USGS EO-1 L1GST:
EO1A1760722013027110KF_1GST

Notice offset of L1GST product
USGS EO-1 L1T : EO1A1760722013027110KF_1T

Co-registered product from USGS
“Flight” co-registration using J. LeMoigne Algorithm
Tx: -13.9456
Ty: -3.7284

Time < 3s on Flight Testbed
Transformation applied by shifting origin
Example of Hyperion L1G Misregistration on Google Earth
ALI L1GST Misregistration on Google Earth
Hyperion Coregistration with 1 Landsat 8 Tile
Tx: -2.743618 Ty -7.184056
ALI L1G Coregistered (Same Scene)

Tx: -13.772506 Ty: -0.815789
Possible Future Work

- Finish/Validate Automated Metrics
- Improve Tile Selection Algorithm
  - Shannon Entropy (Image Histogram) to use Wavelet Entropy
- Automate EO-1 Processing Flow On Matsu Cloud
- Port to CHREC Space Processor (Xilinx MicroZed)
Thank you for your attention!

Questions?

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