### OLI Band Registration Accuracy Algorithm

#### Background/Introduction

The OLI Band Registration Accuracy Assessment Algorithm (BRAA), or the Band-to-Band (B2B) Characterization process, measures the relative band alignment between all bands of each Sensor Chip Assembly (SCA) for the OLI instrument. The displacement for every pair-wise combination of all bands of each SCA requested for assessment is measured; creating an over-determined data set of band-to-band measurements for each SCA. The residuals measured from the B2B characterization process will be used to assess the accuracy of the band-to-band registration of the OLI instrument, and if needed, used as input to the band calibration algorithm in order to calculate new LOS parameters for the CPF.

The B2B characterization process works by choosing tie-point locations within band pairs of each SCA, extracting windows of imagery from each band, and performing grey scale correlation on the image windows. Several criteria are used in determining whether the correlation processing was successful. These criteria include measured displacement and strength of the correlation peak. The subpixel location of the measured offset is calculated by fitting a 2nd order polynomial around the discrete correlation surface and solving for the fractional peak location of the fitted polynomial. The total offset measured is then the integer location of the correlation peak plus the subpixel location calculated. A new fine-resolution least-squares correlation method has been added to the heritage algorithm to provide a more accurate measurement of subpixel offsets. This method is described below.

Several options are available for processing data through the BRAA algorithm. These include choosing evenly spaced points for the location of the windows extracted, choosing to use the geometric grid for determining window locations in order to avoid fill within the image files, specifying the bands and/or the SCA to process, and specifying the valid pixel range to use during correlation. The least-squares correlation method is invoked by requesting image windows with at least one odd dimension, since the heritage algorithm only works with images with even dimensions (e.g., 32x32 image windows will use normalized grey scale correlation, but 31x31 image windows will use least-squares correlation).

An Earth-based acquisition will be used to characterize all bands except the cirrus. A lunar acquisition will be used to characterize the cirrus band. Both types of acquisitions will be passed through BRAA. In terms of the BRAA, it does not matter which type of acquisition is being passed into the algorithm; some of the processing parameters and options may change due to the acquisition type, but both types will use the same mensuration process to create an assessment of the band registration.

#### Dependencies

The OLI BRAA assumes that a cloud-free Earth-viewing L1T or Lunar L1G image has been generated, and depending on the tie-point selection type chosen, that the LOS Model Correction and the LOS Projection and Gridding algorithms have been executed to create a geometric grid file. The L1T/L1G image needs to be in the SCA-separated format and either in a SOM or UTM path-oriented projection for Earth acquisitions. The DOQ control and best available DEM needs to be used in generating the L1T.

#### Inputs

The BRAA and its component sub-algorithms use the inputs listed in the following table. Note that some of these “inputs” are implementation conveniences (e.g., using an ODL parameter file to convey the values of and pointers to the input data).

|  |  |
| --- | --- |
| **Algorithm Inputs** | **Source** |
| ODL file (implementation) |  |
| Calibration Parameter File (baseline) | ODL |
| Correlation Fit Method (see note #14) | CPF |
| Correlation Window Size | CPF or ODL |
| Correlation Maximum Displacement | CPF or ODL |
| Correlation Fill Threshold | CPF or ODL |
| Correlation Minimum Fill Value | CPF or ODL |
| Correlation Maximum Fill Value | CPF or ODL |
| L1T/L1G image | ODL |
| OLI resampling grid (optional) | ODL |
| Outlier (t-distribution) threshold | ODL |
| B2B characterization output file | ODL |
| Output residuals file name | ODL |
| Output statistics file name | ODL |
| SCAs to process | ODL |
| Bands to process | ODL |
| Fill range maximum | ODL |
| Fill range minimum | ODL |
| Fill threshold or percentage | ODL |
| Correlation window size lines | ODL |
| Correlation window size samples | ODL |
| Tie-point spacing in line direction | ODL |
| Tie-point spacing in sample direction | ODL |
| Trending flag | ODL |
| L0R ID (for trending) | ODL |
| Work Order ID (for trending) | ODL |
| Calibration Parameter File (baseline, if trending is requested) | ODL |
| Trending thresholds (Standard deviation line, sample per band per SCA - see note #3). | CPF |

#### Outputs

|  |
| --- |
| Pan downsampled image |
| B2B residuals file (see Table 6‑37 below for details) |
| B2B output data file (see Table 6‑36 below for details) |
| B2B statistics file (see Table 6‑38 below for details) |
| B2B characterization trending (if trend flag set to yes) |
| L0R/L1R ID |
| Work Order ID |
| WRS Path/Row |
| B2B statistics for all band combinations and SCAs |

The processing parameters, listed in the table above and described in the following subsections, can be overridden if they are given as fields within the input ODL file: correlation window size, maximum offset, minimum correlation strength, fill threshold, maximum and minimum file values.

#### Options

Trending on/off switch

Grid-based tie-point generation

Normalized grey scale or least-squares correlation

#### Prototype Code

Input to the executable is an ODL file; output is a set of ASCII files containing measured offsets between band locations with and SCA.

The prototype code was compiled with the following options when creating the test data files:

-g -Wall -march=nocona -m32

The following text is a brief description of the main set of modules used within the prototype, with each module listed, along with a very short description. It should be noted that almost all library modules are not referenced in the explanations below. The modules within the main b2bchar directory of the prototype are discussed, and any library modules that were determined to be important to the explanation of either results, input parameters, or output parameters.

b2b\_char

Main driver for the application. Calls routines to retrieve ODL input and CPF parameters, read and verify image metadata, reduce resolution of the PAN band, create a set of tie-points, and calls the module that will perform correlation on image tie-point locations. Separate calls are made for creating tie-points, depending on whether points are to be evenly spaced or based on a resampling grid.

get\_parms

Reads input ODL parameters. Checks the validity of the input band combinations listed in the ODL file. Reads the CPF BRAA processing parameters.

verify\_band\_combos

Verifies search and reference band combinations given as input. Verification is done by matching the reference and search band list; if bands given do match, an error is returned.

create\_tie-points

Driver for creating evenly spaced tie-points. Calls det\_tie-points for each band combination storing tie-point locations in GCPLIB data structure.

det\_tie-points

Calculates a set of evenly spaced tie-point locations based on image size. Tie-points are based on number of points given as an input ODL parameter and the size of the image file.

create\_tie-points\_grid

Driver for creating tie-points based on the resampling grid.

downsample

Main driver for reducing the resolution of the PAN band. Driver calls modules to initialize reduce image file (setup\_reduce\_img), calculates cubic convolution weights (cubic\_convolution\_weights), and applies cubic convolution weights to the PAN band (reduce).

setup\_reduce\_img

Initializes PAN reduced image file creation.

cubic\_convolution\_weight

Determines cubic convolution weights.

reduce

Applies cubic weights to the PAN band. Output is written to file created/initialized in setup\_reduce\_img.

b2b\_corr

Main driver for band correlation, or band mensuration, process. Driver opens image, calls module to perform correlation at tie-point locations (process\_gcp), and writes out band registration residuals file (Table 6‑22). process\_gcp is called on for each SCA and band combination given in the input ODL file.

process\_gcp

Process to perform correlation between two bands for one SCA. See Ground Control Point Correlation ADD for information on the L8/9 correlation modules and process. Calls module xxx\_check\_fill to determine if a given window of imagery contains enough "non-fill" pixels so that mensuration can be performed.

ias\_math\_check\_pixels\_in\_range

Checks to see if percent of pixels within a given buffer contains fill. Fill is passed in as a parameter. Module has been modified so that fill is a range rather than a single value.

math\_fine\_corr

Math library routine that implements the new (see below) least-squares correlation algorithm developed for fine subpixel offset measurement. Takes the same-size reference and search image windows as input and returns measured offsets.

#### Procedure

Band Registration Accuracy Assessment measures the misalignment between spectral bands after all known geometric effects have been taken into account. The results from the band registration assessment are used by the band alignment calibration routine (See Band Alignment Calibration ADD) to estimate new Legendre LOSs (See Line-of-Sight Model Creation ADD) for each band of each SCA. Due to the different viewing angles for each band of each SCA, geometric displacement due to relief must be removed from the imagery for band-to-band characterization of Earth acquisitions, i.e., input imagery for band registration assessment must be precision- and terrain-corrected (See Resampling ADD). Figure 6‑73 shows the steps involved in band registration assessment, and include creating data sets with common pixel resolutions; choosing locations (tie-point locations) for measurement; performing mensuration; removing outliers from calculated residuals; and calculating statistics from the remaining residuals. Residuals are measured for each band combination of each SCA that is requested through the input parameters.

##### 

Figure 6‑41. Band Registration Accuracy Assessment Block Diagram

The OLI Band Registration Accuracy Assessment algorithm has heritage in the L7 and ALI IAS B2B Characterization (B2B Char) algorithm/process. The prototype code for OLI BRAA will contain many of the same modules that are present in the L7 and ALI IAS B2B Char. The core functions taken from ALIAS for the band-to-band assessment processes that will be needed for OLI processing are specified where applicable. Changes that may be necessary within these modules are briefly discussed. The correlation and mensuration modules, however, are not described within this ADD, as they are already present within the Ground Control Correlation ADD; this ADD should reviewed for any information pertaining to these processes. Also, it should be noted that changes due to items such as file format, which are not either instrument specific or due to changes to the algorithm, are not discussed.

##### Stage 1 - Data Input

The data input stage involves loading the information required to perform the band registration assessment. This includes reading the image file, retrieving the output B2B file names: output, residuals and statistic files; retrieving or initializing processing parameters: maximum displacement, fill range, fill threshold, minimum correlation peak, t-distribution threshold, SCAs to process, bands to process, correlation window size, trending thresholds, tie-point method; and if the tie-point method is set to grid-based, the geometric grid file name will be read. Once the input file (and, if needed, the geometric grid name) has been retrieved, the files and the information stored within them can be opened and read.

##### Stage 2 - Creating a Reduced Resolution PAN band

Before displacement between the PAN band and the other multispectral bands can be measured, the PAN band must be reduced in resolution to match that of the multispectral bands. An oversampled cubic convolution function is used to reduce the resolution of the PAN band. Cubic convolution interpolation uses a set of piecewise cubic spline interpolating polynomials. The polynomials have the following form:



Since the cubic convolution function is a separable function, a two-dimensional representation of the function is given by multiplying two one-dimension cubic convolution functions, one function representing the x-direction the other function representing the y-direction. For an offset of zero, or x = 0, and α = -1.0, the discrete cubic function has the following values: f(0) = 1 and f(n) = 0 elsewhere. Therefore, convolving the cubic convolution function of x = 0 with a data set leaves the data set unchanged.



Figure 6‑42 shows the cubic function f(t) (dashed line) and the corresponding discrete weights for an offset, or phase, of zero (crossed-dots).

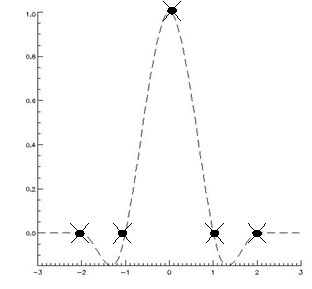


Figure 6‑42. Cubic Convolution Function and Weights for Phase of Zero

To spatially scale an input data stream, an oversampled cubic convolution function with an offset of x =0 can be used. This can best be understood by looking at the Fourier Transform scaling property of a function that is convolved with a given input data set:





Where:



● is multiplication

*F* is the Fourier transform of *f*

*X* is the Fourier transform of *x*

*t* is time

ω is frequency

Applying the cubic function and scaling properties to an image data file shows that densifying the points applied with the cubic convolution function will, in turn, inversely scale the function in the frequency domain, therefore reducing the resolution of the imagery. By setting the cubic convolution offset to zero, densifying the number of weights of the cubic function, and convolving these weights to an image file, a reduction in resolution will be the resultant output image file. Figure 6‑43 shows the cubic function with corresponding weights densified by a factor of two and a phase shift of zero. To ensure that the cubic weights do not scale the DNs of the output imagery during convolution, the cubic weights are divided by the scale factor.



Where:

*fs*[n] = scaled cubic convolution weights

*f*(n) = cubic convolution function

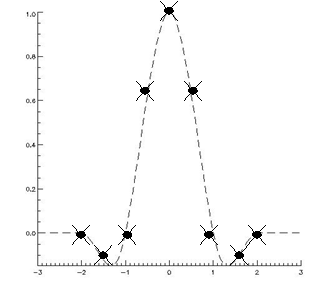


Figure 6‑43. Cubic Convolution Densifyied by a Factor of 2

Scaling the cubic convolution function by a factor of 2 gives the following one-dimensional set of weights:



To determine the two-dimensional cubic convolution weights, two one-dimensional sets of cubic weights are multiplied together (note only 7 values are needed for ccw, outside of this extent the weights are zero):



Where:

ccw[n] is a 8x1 one-dimensional set of cubic weights

ccw[m] is a 1x8 one-dimensional set of cubic weights

###### Procedure for Reducing PAN band

To reduce the resolution of the PAN band, apply the ccw[n,m] weights to the PAN image data:



Note: The number of lines and number of samples listed below pertain to the size of the PAN band imagery.

Reduce PAN Band Resolution Processing Steps

1. Set line =0 then for every other PAN line
   1. Set sample = 0 then for every other PAN sample
   2. initialize summing variable sum = 0.0
   3. For m = -4 to 4
      1. For n = -4 to 4
      2. Check to see if current image index is within valid imagery
      3. if m + line < 0 then line index = -m - line

else if m + line >= number of lines then line index =

2 \* number of lines - m - line - 1

else line index = m + line

* + 1. if n + sample < 0 then sample index = -n - sample

else if n + sample >= number of sample then sample index = 2 \* number of samples - n - sample - 1

else sample index = n + sample

* + 1. sum = sum + ccw[n+4,m+4] • pan[line index, sample index]
  1. Store output DN for reduced PAN

output line = line / 2

output sample = sample / 2

reduce pan[output line, output sample] = sum

##### Stage 3 - Create Tie-point Locations

Tie-point locations may be determined in an evenly spaced pattern in output space, or they may be established in an evenly spaced pattern in input space, using the OLI geometric grid.

###### Determine Evenly Spaced Tie-points (See notes #6 and #7)

To determine evenly spaced tie-point locations, a tie-point location is defined by stepping through the output space of the imagery by the user-defined steps N,M.

Create Evenly Spaced Tie-Points Processing Steps

1. Determine the number of tie-points in the sample and line direction:



Where:

M = user-entered number of tie-points in the sample direction

N = user-entered number of tie-points in the line direction

ONS = number of samples in the output space of the multispectral band

ONL = number of lines in the output space of the multispectral band

Correlation window samples = user-entered correlation window size in samples

Correlation window lines = user-entered correlation window size in lines

1. Set evenly spaced tie-point locations.
   1. For j = 0 to N-2



* 1. 
  2. For i = 0 to M-2



* 1. 

###### Determine Geometric Grid Spaced Tie-points (See notes #6 and #7)

For descriptions of the format and data stored within the geometric grid, see the Line of Sight Projection to Ellipsoid and Terrain ADD.

Geometric Space Tie-points Processing steps

1. Read the image extent parameters from the geometric grid.

INS = input (raw) space number of samples

INL = input (raw) space number of lines

2. Determine the number of tie-points in the sample and line direction:



3. Establish the input (raw) space tie-point locations.

3.1 For j = 0 to N-2



3.2 

3.3 For i = 0 to M-2



3.4

4. Project inputs space tie-points locations to output space.

4.1 For j=N-1

4.1.1 For i=M-1

Map the input space tie-point location to the output space using grid mapping coeffcients.

tie-point location y = b0 + b1 \* x[i] + b2 \* y[j] + b3 \* x[i] \* y[j]

tie-point location x = a0 + a1 \* x[i] + a2 \* y[j] + a3 \* x[i] \* y[j]

Where (See note #7):

an = geometric grid forward sample mapping coefficients for the zero elevation plane retrieved from the resampling grid

bn = geometric grid forward line mapping coefficients for the zero elevation plane retrieved from the resampling grid

##### Stage 4. Calculate Individual Point-by-Point Band Displacements

Normalized cross correlation is the standard method used to measure spatial differences between the reference and search windows extracted from the two bands being compared. The normalized cross correlation process helps to reduce any correlation artifacts that may arise from radiometric differences between the two image sources. The correlation process will only measure linear distortions over the windowed areas. By choosing appropriate correlation windows that are well distributed throughout the imagery, nonlinear differences between the image sources can be found. Normalized grey scale correlation has the following formula:



Where:

N = M = Correlation window size in lines and samples

*R =* correlation surface (N,M) (See note# 10)

F = reference window (N,M)

G = search window (N,M)





Normalized cross correlation will produce a discrete correlation surface (i.e., correlation values at integer x,y locations). A subpixel location associated with the displacement is found by fitting a polynomial around a 3x3 area centered on the correlation peak. The polynomial coefficients can be used to solve for the peak or subpixel location. Once the discrete correlation has been calculated and the peak value within these discrete values has been found, the subpixel location can be calculated:



Where

P(x,y) is polynomial peak fit

x = sample direction

y = line direction

Set up matrices for a least-squares fit of discrete R(x,y) to x/y locations.



or: [Y] = [X] [a]

Note that R(x,y) is relative to the peak; the total offset will need to have the integer line offset and sample offset added to the subpixel location to have the total measured offset. Solving for the peak polynomial using least squares:



Calculating the partial derivative of P(x,y) in both the x and y directions, setting the partial equations to zero, and solving the partials for x and y, gives the subpixel location within the subpixel 3x3 window.





Set partial equations equal to zero and solve for x and y:

Subpixel 

Subpixel

The processing steps subsection provides the steps for mensuration, calculating the total offset measured, and how they fit in the overall procedure.

See the Ground Control Point Correlation ADD for prototype specifications of the normalized grey scale correlation processes.

*Least Squares Fine Correlation Method*

The band-to-band and image-to-image accuracy characterization algorithms also provide a second, least-squares based correlation method that can be used to measure subpixel image displacements somewhat more reliably than the cross-correlation/peak finding method used for general purpose correlation. This is useful for band registration measurements where the displacements should always be much less than a pixel, and where the quadratic peak finding method can introduce small offset-dependent biases in the measurements. This method requires that the reference and search image windows be the same size and that the offsets to be determined be less than 1 pixel. Since the normalized grey scale correlation algorithm does not work on image windows whose dimensions are not even numbers, this least squares correlation method is invoked if either window dimension is an odd number.

The least-squares correlation method uses the reference and search image window pixels to estimate the sample offset (sample), line offset (line), gain, and bias adjustments that best match the (sample, line) shifted and bilinearly interpolated search image to the radiometrically adjusted (1+gain, bias) reference image. The 3x3 pixel image subwindow surrounding each interior (non-edge) image pixel in the reference and search windows provides one observation for purposes of estimating the four adjustment parameters, using the following model:

S0 + Sx \* sample + Sy \* line + Sxy \* sample \* line = R0 \* (1+gain) - bias

Where:

S0 = Si,j = the central pixel in the 3x3 search subwindow centered at (i,j)

Sx = (Si+1,j – Si-1,j)/2 = slope estimate in the sample direction

Sy = (Si,j+1 – Si,j-1)/2 = slope estimate in the line direction

Sxy = (Si+1,j+1 + Si-1,j-1 – Si+1,j-1 - Si-1,j+1)/4 = rate of slope change

R0 = Ri,j = the reference image pixel corresponding to Si,j

This can be reorganized into an observation model for the 4 fit parameters:

Sx\*sample + Sy\*line - R0\*gain + bias = R0 - S0 - Sxy\*sample\*line

Or:



[ 1 x 4 ] [4 x 1 ] = [ 1 x 1 ] Array sizes

Note that this equation is not linear (since sample and line appear on the right side) and must be solved iteratively.

Each non-edge pixel generates an observation of this form:

[Xi,j]T [coef] = [Yi,j]

Where:

[Xi,j]T = [ Sx Sy -R0 1 ] (1x4 matrix)

[coef] = [ sample line gain bias ]T (4x1 matrix)

[Yi,j] = [ R0 – S0 – Sxy sample line ] (1x1 matrix)

Taken together, these observations can be used to compute the best fit, in the least-squares sense, values for the four fit parameters:

[N] =  [Xi,j] [Xi,j]T (4x4 matrix)

[C] =  [Xi,j] [Yi,j]T (4x1 matrix)

[coef] = [N]-1 [C] (4x1 matrix)

The computed values of the fit parameters in [coef] are used to update the [Yi,j] values for each iteration.

The solution procedure is as follows:

1. Verify that the input reference and search windows are the same size and that the window dimensions are both at least 3 pixels.
2. Initialize the least-squares solution normal equations:
   1. Set all 4 elements of the 4x1 constants vector **C** to zero.
   2. Set all 16 elements of the 4x4 normal equation matrix **N** to zero.
   3. Set the normal equation diagonal term corresponding to the gain parameter, **N**[2][2], to 1/g2, where g is the apriori standard deviation of the gain parameter, set to 0.05 (5%) to limit the magnitude of the gain adjustment.
   4. Set the normal equation diagonal term corresponding to the bias parameter, **N**[3][3], to 1/b2, where b is the apriori standard deviation of the bias parameter, set to 5 DN to limit the magnitude of the bias adjustment.
   5. Initialize the four adjustment parameter values to zero.
3. Iterate the solution the times. For each iteration:
   1. Loop through the non-edge image pixels, Si,j, Ri,j, in the Nsamp by Nline image windows, where 0 < i < Nsamp-1 and 0 < j < Nline-1. For each pixel:
      1. Compute S0, Sx, Sy, and Sxy from the 3x3 search subwindow surrounding the current pixel, using the equations above.
      2. Compute the right side of the observation equation using R0 and the current estimates of sample and line:

RHS = R0 – S0 – Sxy \* sample \* line

* + 1. Add this observation to the normal equations:

**N**[0][0] += Sx \* Sx

**N**[0][1] += Sx \* Sy

**N**[0][2] -= Sx \* R0

**N**[0][3] += Sx

**C**[0] += Sx \* RHS

**N**[1][1] += Sy \* Sy

**N**[1][2] -= Sy \* R0

**N**[1][3] += Sy

**C**[1] += Sy \* RHS

**N**[2][2] += R0 \* R0

**N**[2][3] -= R0

**C**[2] -= R0 \* RHS

**N**[3][3] += 1

**C**[3] += RHS

* 1. Complete the symmetric normal equation matrix:

**N**[1][0] = **N**[0][1]

**N**[2][0] = **N**[0][2]

**N**[2][1] = **N**[1][2]

**N**[3][0] = **N**[0][3]

**N**[3][1] = **N**[1][3]

**N**[3][2] = **N**[2][3]

* 1. Solve the normal equations:

**X** = [ sample line gain bias ]T = **N**-1 **C**

1. Return the results of the final iteration:

Fit\_offset[0] = sample

Fit\_offset[1] = line

Diag\_Displacement = sqrt( sample \* sample + line \* line )

##### Stage 5. Removing Outliers Using the t-distribution

Once all of the line and sample offsets have been measured and the first level of outlier rejection has been performed, and a check against the maximum allowable offset and the minimum allowable correlation peak takes place, the measurements are further reduced of outliers using a Student-t outlier rejection.

Given a t-distribution tolerance value, outliers are removed within the data set until all values deemed as “non-outliers” or “valid” fall inside the confidence interval of a t-distribution. The tolerance, or associated confidence interval, is specified per run (or processing flow) and usually lies between 0.9-0.99. The default value is 0.95. The number of degrees of freedom of the data set is equal to the number of valid data points minus one. The steps involved in this outlier procedure are below. The process listed works on lines and samples simultaneously, calculating statistics independently for each.

**Student-t Outlier Rejection Processing Steps**

1. Calculate the mean and standard deviation of data for lines and samples (see stage #6).





Where:

N = number of valid offsets measured (above the peak threshold and below the maximum offset)

Two means and standard deviations are calculated, one for the line direction and one for the sample direction.

1. Find the largest offset and compare it to outlier threshold.
   1. Calculate the two-tailed t-distribution (T) value for the current degree of freedom (N-1) and confidence level α.
   2. Calculate the largest deviation from the mean allowable for the specified degree of freedom and α:

Δline = σline\* T

Δsample = σsample\* T

Where:

σline = standard deviation of valid line offsets

σsample = standard deviation of valid sample offsets

* 1. Find the valid data point that is farthest from the mean.

max linei = MAX{ line offset - mean line offset}

max samplej = MAX{ sample offset - mean sample offset}

Where:

The maximum is found from all valid offsets

i is the tie-point number of max line

j is the tie-point number of max sample

* 1. If the valid data point that is farthest from the mean is greater than the allowable Δ, then the valid point is flagged as outlier.

if max linei > Δline or max samplej > Δsample, then

if( max samplej / σsample > max linei / σline )

tie-point j is marked as an outlier

else

tie-point i is marked as an outlier

else no outliers found

1. Repeat 1 and 2 above until no outliers are found.

##### Stage 6. Calculating Measured Statistics

The mean, standard deviation, minimum, maximum, median, and RMS offset are calculated from the tie-points that pass all outlier criteria: below maximum offset, above peak threshold, and student t-distribution test. The calculation for mean, standard deviation, and RMS are below, where xi is the measured offset.

mean: 

standard deviation: 

RMS: 

###### Band Accuracy Assessment Processing Steps

Windows extracted from imagery have the user-entered dimensions, correlation window lines, and correlation window samples. Correlation parameters have been read or set as default values: maximum offset, fit method, correlation peak, fill data range, fill threshold. The bands should be indexed so that the PAN band is always used as a reference to all other bands.

1. For SCA = Number of SCAs to process
   1. For rband = Number of OLI bands to process

if rband is equal to PAN, use the reduced PAN image file

* 1. For sband = rband + 1 to Number of OLI bands to process
  2. For index = Number of tie-points to process
     1. Read the current tie-point chip and tie-point location x,y

Set the tie-point flag to unsuccessful

* + 1. Extract the sband window (of imagery) at tie-point location x,y
    2. Extract the rband window (of imagery) at tie-point location x,y
    3. Count the number of pixels in rband window that is within fill range.

count = 0

For i=0 to number of pixels in correlation window

If rband pixel is > fill min and rband pixel is < fill max

count++

* + 1. Check the number of rband pixels counted against the fill threshold/percentage.



increment index to next tie-point location

else

continue

* + 1. Count the number of pixels in the sband window that is within the fill range.

count = 0

For i=0 to number of pixels in the correlation window

If sband pixel is > fill min and sand pixel is < fill max

count++

* + 1. Check the number of sbands pixels counted against the fill threshold/percentage.



Increment the index to next tie-point location

else

continue

* + 1. Perform normalized grey scaled correlation between the rband and sband windowed images, calculating correlation surface *R* (See Stage 4 and notes #9 and #10).
    2. Find the peak within the correlation surface

Max = *R*(0,0)

For i=0 to correlation window number of lines -1

For j=0 to correlation window number of samples -1

If *R*(i,j) > max then

Max = *R*(i,j)

line offset = i

sample offset = j

* + 1. Check the correlation peak against the threshold

if max > peak threshold

continue

else

set the tie-point flag to outlier and choose next tie-point

* + 1. Measure the subpixel peak location (see stage #4)

Δsub-line

Δsub-sample

* + 1. Calculate the total pixel offset

total line offset = line offset + Δsub-line

total sample offset = sample offset + Δsub-sample

* + 1. Check the offset against the maximum displacement offset



if ( total displacement > maximum displacement )

Set the tie-point flag to outlier and choose the next tie-point

Else

Set the tie-point flag to valid

* 1. Store SCA and band combination (rband-to-sband) tie-point mensuration information, correlation success, and offsets measured. See table 6.21.

1. For SCA = 1 to Number of SCAs to process
   1. For band combination = 1 to Number of band combinations
      1. Perform t-distribution outlier rejection (See stage #5).
   2. Store the SCA and band combination final individual tie-point information and outlier flag. See table 6.22.
2. For SCA = 1 to Number of SCAs to process
3. For band combination = 1 to Number of band combinations
   1. Calculate the mean, minimum, maximum, median, standard deviation, and root mean squared offset.
   2. Store the SCA and band combination statistics. See table 6.23.
4. Perform trending if trending flag is set to yes
   1. Check the results against the trending thresholds

For each band of each SCA

if measured Standard Deviation > trending threshold

exit trending

If there are no Standard Deviation > trending thresholds perform trending

#### Output files

The output files listed below for the BRAA follow the philosophy of the ALIAS B2B Characterization output files in that they are made generic so that the same format can be used elsewhere. Therefore, some fields, such as latitude, longitude, and elevation, may not apply to the application and would be filled with zeros or nominal values.

All output files contain a standard header. This standard header is at the beginning of the file and contains the following:

* Date and time the file was created
* Spacecraft and instrument pertaining to measurements
* Off-nadir (roll) angle of the spacecraft/instrument
* Acquisition type
* Report type (band-to-band)
* Work order ID of process (left blank if not applicable)
* WRS path/row
* Software version that produced the report
* L0R image file name

The data shown in Figure 6‑22 is stored in the database. The statistics stored per band per SCA will be used for trending analysis of the band registration accuracy of the OLI instrument. Results produced through a time-series analysis of this data stored, over a set time interval or multiple image files, will determine if new LOS Legendre coefficients will need to be generated from the OLI Band-to-Band Calibration Algorithm (See OLI Band-to-Band Calibration ADD for details). These statistics may also be needed for providing feedback to the L8/9 user community about the band registration of the L8/9 products generated.

|  |  |
| --- | --- |
| **Field** | **Description** |
| Date and time | Date (day of week, month, day of month, year) and time of file creation. |
| Spacecraft and instrument source | Landsat 8/9 and OLI (TIRS if applicable) |
| Processing Center | EROS Data Center SVT |
| Work order ID | Work order ID associated with processing (blank if not applicable) |
| WRS path/row | WRS path and row (See note #11) |
| Software version | Software version used to create report |
| Off-nadir angle | Off-nadir roll angle of processed image file (See note #12) |
| Acquisition Type | Earth viewing or Lunar |
| L0R image file | L0R image file name used to create L1T |
| Processed image file name | Name of L1T used to create report |
| Reference bands | Reference bands used in band assessment |
| Search bands | Search bands used in band assessment |
| Heading for individual tie-points | One line of ASCII text defining individual tie-point fields. |
| For each tie-point: |  |
| Tie point number | Tie-point index/number in total tie-point list |
| Reference line | Tie-point line location in reference image (band) |
| Reference sample | Tie-point sample location in reference image (band) |
| Reference latitude | Tie-point latitude location |
| Reference longitude | Tie-point longitude location |
| Reference elevation | Elevation of tie-point location (see note #13) |
| Search line | Tie-point line location in search image |
| Search sample | Tie-point sample location in search image |
| Delta line | Measured offset in line direction |
| Delta sample | Measured offset in sample direction |
| Outlier flag | 1=Valid, 0=Outlier |
| Reference band | Reference band number |
| Search band | Search band number |
| Reference SCA | SCA number that reference window was extracted |
| Search SCA | SCA number that search window was extracted |
| Search image | Name of search image |
| Reference image | Name of reference image |

Table 6‑21. Band Registration Accuracy Assessment Data File

|  |  |
| --- | --- |
| **Field** | **Description** |
| Date and time | Date (day of week, month, day of month, year) and time of file creation. |
| Spacecraft and instrument source | Landsat 8/9 and OLI (TIRS if applicable) |
| Processing Center | EROS Data Center SVT |
| Work order ID | Work order ID associated with processing (blank if not applicable) |
| WRS path/row | WRS path and row (See note #11) |
| Software version | Software version used to create report |
| Off-nadir angle | Off-nadir pointing angle of processed image file (See note #12) |
| Acquisition Type | Earth viewing or Lunar |
| L0R image file | L0R image file name used to create L1T |
| Processed image file name | Name of L1T used to create report |
| Number of records | Total number of tie-points stored in file |
| Heading for individual tie-points | One line of ASCII text defining individual tie-point fields. |
| For each band combination |  |
| Combination header | Number of points in combination, reference band number, search band number. |
| For each tie-point: |  |
| Tie point number | Tie-point index/number in total tie-point list |
| Reference line | Tie-point line location in reference image (band) |
| Reference sample | Tie-point sample location in reference image (band) |
| Reference latitude | Tie-point latitude location |
| Reference longitude | Tie-point longitude location |
| Reference elevation | Elevation of tie-point location |
| Search line | Tie-point line location in search image |
| Search sample | Tie-point sample location in search image |
| Delta line | Measured offset in line direction |
| Delta sample | Measured offset in sample direction |
| Outlier flag | 1=Valid, 0=Outlier |
| Correlation coef | Correlation coefficient for tie point correlation |
| Reference band | Reference band number |
| Search band | Search band number |
| Reference SCA | SCA number that reference window was extracted from |
| Search SCA | SCA number that search window was extracted from |
| Search image | Name of search image |
| Reference image | Name of reference image |

Table 6‑22. Band Registration Accuracy Assessment Residuals File

|  |  |
| --- | --- |
| **Field** | **Description** |
| Date and time | Date (day of week, month, day of month, year) and time of file creation. |
| Spacecraft and instrument source | Landsat 8/9 and OLI (TIRS if applicable) |
| Processing Center | EROS Data Center SVT |
| Work order ID | Work order ID associated with processing (blank if not applicable) |
| WRS path/row | WRS path and row (See note #12) |
| Software version | Software version used to create report |
| Off-nadir angle | Off-nadir pointing angle of processed image file (See note #13) |
| Acquisition Type | Earth viewing or Lunar |
| L0R image file | L0R image file name used to create L1T |
| Processed image file name | Name of L1T used to create report |
| t-distribution threshold | Threshold used in t-distribution outlier rejection |
| For each band combination of each SCA processed |  |
| Reference band | Reference band of statistics |
| Search band | Search band of statistics |
| SCA | SCA number of statistics |
| Total tie-points | Total number of tie-points for band combination of SCA |
| Correlated tie-points | Number of tie-points that successfully correlated for band combination of SCA |
| Valid tie-points | Total number of valid tie-points for band combination of SCA after all outlier rejection has been performed |
| For both line and sample direction: | All statistics are given in terms of pixels |
| Minimum offset | Minimum offset within all valid offsets |
| Mean offset | Mean offset of all valid offsets |
| Maximum offset | Maximum offset within all valid offsets |
| Median offset | Median offset within all valid offsets |
| Standard deviation | Standard deviation of all valid offsets |
| Root-mean-squared | Root mean squared offset of all valid offsets |

Table 6‑23. Band Registration Accuracy Assessment Statistics Output File

##### Assessing Band Registration (Accessing Statistics Stored in Database)

The geometric CalVal team will need to access the Band Accuracy Assessment statistics stored in the database. Delineation, or essentially data base querying, will take place by the following or a combination of the following:

* Date range of the image acquisition or processing date
* By SCA number
* By band number
* By acquisition type (Nadir, off-nadir, Lunar)
* By geographic location of image extent

At a minimum, access to the Band Accuracy Assessment statistics is needed. Simple tools, such as an SQL queries, would be beneficial to the geometric CalVal team, but are not absolutely necessary, as they could be developed later through other means.

#### Maturity

#### Notes

Some additional background assumptions and notes include the following:

* Correlation parameters, minimum correlation peak, and maximum offset are stored and retrieved from the CPF.
* Options need to be available for generating statistics; scene statistics, individual bands per SCA, SCA summary, band summary. These statistics would be provided to the user as summary statistics to be provided as image quality assessment to the user community.
* There will need to be a set of criteria, based on calculated statistics, as to whether trending should be performed. These criteria would be provided to avoid having garbage stored in the database. Any values needed in determining whether the criteria have been met for trending would be stored and retrieved from the CPF. There would be one threshold per band per SCA. The criteria to check for trending are shown in section 5.1 of the Band Accuracy Assessment Processing steps section.
* Band Accuracy statistics stored within the database will be accessed for analysis.
  + *Accessed according to a specific date range.*
  + *Accessed according to a specific band or SCA.*
  + *Accessed according to a specific geographic location.*
  + *Accessed according to acquisition type (nadir, off-nadir, lunar).*
  + This data accessed will be retrieved and stored within a comma-delimited file. The methodology used to access the database could be an SQL script. This SQL query code could be developed either by the IPE or outside of the IPE.
* Data stored within the database will be accessed for time series analysis.
  + Data would be pulled out by scene/SCA band pairs for a user-specified time.
  + Statistics over multiple scenes would be calculated per SCA and/or per band, and then combined into the SCA and/or band average statistics.
  + Results could be compared to the band registration spec. These results could serve as triggers to other events, i.e., new CPF generation and testing.
  + Results could be used to verify conformance with product specifications.
  + These calculations could be performed within the methodology used to access the data from the database (SQL script).
* Tie-point locations could also be stored and used as projection Y and X coordinates. The appropriate conversions must be done when converting between projection coordinates and line and sample locations when extracting image windows between bands. This transformation should also include any rotation due to path-orientated projections.
* The prototype code uses a library call that maps any input point with a given elevation to output space. For BRAA, the elevation for the mapping point is set to zero. Since the reference and search output space are the same for BRAA, the output line/sample in output reference space should be the line/sample in output search space.
* The c and d parallax coefficients are needed for each band or each SCA for every grid cell point. Therefore, if the coefficients were stored as arrays stacked by grid column, and then grid row for a particular input pixel that fell within grid cell column N and grid cell row M, the c and d coefficients needed for that pixel would be indexed by: index = (M \* number of grid columns + N) \* 2. The factor of 2 is because the parallax odd/even effects are mapped as linear; therefore, 2 coefficients are stored for each the odd and even pixels of a grid cell.
* The grey scale correlation process, or surface, can be implemented using a Fast Fourier Transform (FFT).
* The correlation surface could be smaller than the search window, depending on the search area or maximum offset.
* Any kind of "non-WRS" collect, such as lunar, should have 000/000 listed as the path/row.
* The pointing angle for lunar acquisitions would be 0.0.
* This tie-point residual file structure is also used for the image registration accuracy characterization algorithm, so it includes fields that are not required for both algorithms. An example is the elevation field, which is set to 0 for this algorithm.
* The correlation result fit method defines the algorithm used to estimate the correlation peak location to subpixel accuracy. Only the quadratic surface fitting method described in this ADD is supported in the baseline algorithm. The Least-Squares Correlation technique does not use the surface-fitting method; for the grey scale correlation technique, the peak fitting method still applies.