CANOPUS ASI SUPPORT CONTRACT

Final Report for Task 6, Part 3

Application of ASI Calibration Factors

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Application of ASI Correction Factors

1. ASI Data Description

The CANOPUS allsky imager is an intensified imager using a 256x256-element CCD detector. Its imaging and signal processing circuits are linear over a wide range of input light intensities. The ASI employs a 12-bit analog to digital converter, which can be used to produce 12-bit image data at exposure times ranging from 0.1 seconds to 65 seconds. Additionally, in order to increase the camera dynamic range, up to 256 single-frame exposures may be summed into a resultant 16-bit image frame. However, to guarantee non-saturation due to over-summing, the maximum number of 12-bit images summed into the final 16-bit image is 16. This gives the camera a maximum numerical range of 16x4095 = 65520. In the present ASI operations, the camera is used in a mode wherein it sums 8, 12-bit images into the final 16-bit image, resulting in a maximum numerical dynamic range of (4095x8 = 32760).

Note: The present 8-frame summation is an historical artifact resulting from a change of mode in the field, and the system should probably be readjusted to operate in the original 16-frame summation mode to achieve maximum numerical dynamic range.

In the present operational mode, the 16-bit image data is processed to reduce the volume of data sent over the satellite link. First, the image is cropped by removing all pixels outside of a radius of 100 pixels from the nominal center of the array. This results in a data volume reduction of about 50%. Note that the "centre" of the cropping operation does not change from year-to-year, and so this "centre" is not actually in the camera zenith. This is done to avoid impacts on the data handling software at the receiving end.

After cropping, the image data is compressed. If the original pixel value is 1023 or less, it is divided by 16. If greater than 1023, it is compressed logarithmically, with the degree of compression suited to the remaining numerical dynamic range (1024-65535). This results in another 50% reduction in data volume. The resulting images contain 30,896 8-bit pixels.

2. Calibration Methodology

The transformation of raw ASI data numbers to physical units can be understood as a series of steps. There are both geometric and quantitative transformations to perform and the sequence is important because the quantitative corrections are meant to be applied in the original CCD coordinate frame.

Step 1. Decompression

The raw ASI DN are converted to "original" DN using the algorithm:

```
if (Din < 64) Dout = din * 16
else Dout = dout = s*exp(din*alpha)

where alpha = ln(65535/1024)/(255-64) = .0217742 and

s = 1024*exp(-64*alpha)
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This decompression must be performed on all ASI data frames before further processing.

Step 2. Dark Frame Preparation

The ASI transmits two dark frames each hour. These should be decompressed as in step 1, and averaged together. ASI also transmits four dark reference pixels in the header information of every image, including the hourly dark frames. These pixels represent the mean levels in four 10x10-pixel areas in the four corners of each image. This information can be used to "correct" the hourly dark frames prior to dark frame subtraction. This step should only be necessary if the CCD temperature is out of control, but will do no harm if included in routine processing. This scheme was implemented to combat temperature drift of the CCD, but now that the CCD temperature is actively controlled, the dark frame correction described here should no longer be necessary.

The first two dark reference pixels are taken from the top of the array, and represent the mean dark level of image row 14.5. The last two dark reference pixels are taken from the bottom of the array, and represent the mean dark level of image row 240.5. Linear interpolation and scaling are used to correct the hourly dark frame. The correction algorithm is:

From the two hourly dark frames (HDa,HDb) produced in minute 01 of each hour: Hda and HDb refer to the two 256x256 dark frame arrays, HDa(i,j) and HDb(i,j) refer to pixels in these arrays in HDa(col,row) format. All processing assumes decompression has been performed on ALL pixel values.

Step 3. Calibration Reference Correction ("Q" array)

The ASI produces hourly calibration image frames. These are included as a continuous check on the ASI system responsivity. The "Q" array is also an image of the internal ASI calibration source, produced in the laboratory, at a time when the ASI responsivity is known. Thus, the "Q" array is used to correct the ASI response DN levels using the hourly calibration frames. The assumption being that if the DN levels in the hourly calibration have changed, then the camera responsivity has changed, and we need to scale the DN levels in proportion to the reference calibration frame ("Q" array).

So, the correction is as follows:

For the two hourly calibration frames:

decompress

subtract the averaged hourly dark frames, if necessary, using the dark level correction scheme of step 2, or:

$$HC' = HC - HD$$

where HC = hourly calibration images (averaged)
HD = hourly dark frames (averaged)
HC' = dark-subtracted hourly calibration image

The "Q" array contains a peak level (PQ), and a number less than 1 for each pixel in the image array. So, correct for the calibration drift by scaling the ASI dn by the ratio of the hourly image to the reference image (Q).

$$I''(i,j) = I'(i,j) * HC'(i,j) / (PQ * Q(i,j))$$

where I'' is now the response-corrected, dark-subtracted image.

Step 4. Uniformity Correction ("P" Array)

The "P" array is an image array containing numbers less than 1. It contains scale factor corrections for ASI response falloff with zenith angle, and small-scale, fixed-pattern irregularities. The correction is applied as a division of the ASI data:

$$I'''(i,j) = i''(i,j) / P(i,j)$$

Step 5. Conversion to Physical Units (Rayleighs)

It remains to convert to Rayleighs from DN, and to normalize to one second exposure time. The camera exposure time for all images is 1.664 seconds. For a given image, the "R" factor for the 5577 or 6300 filter applies. The final correction to Rayleighs is then

$$R(i,j) = I'''(i,j) / (R5577 * 1.664), \text{ etc.}$$

where R(i,j) is the pixel value in Rayleighs.

Step 6. Geometric Transformation

The final correction is a geometric correction to convert pixel locations in the ASI images to coordinates in the local (Gillam) reference frame. This requires two corrections. The camera optical system deviates from a perfect equidistant-projection lens system at large zenith angles. This causes a nonlinear compression of the radius of an image on the CCD. Secondly, the ASI image must be rotated about three axes to correct for misalignment of the ASI upon it's podium at Gillam.

We adopt three Cartesian axes, x (North-South), y (West-east), and z (zenith) to define the local, fixed (topocentric) coordinate system. We define two angles, theta, the angle between the z axis and the zenith, and phi, the azimuth of the x-axis. The alignment process is a set of rotations about the three axes of the general form:

$$R[a] = \begin{vmatrix} \cos(a) & -\sin(a) & 0 \\ \sin(a) & \cos(a) & 0 \\ 0 & 0 & 1 \end{vmatrix}$$

and an arbitrary alignment can be obtained from a composite rotation:

Rz[g] : rotation of ASI about optic axis;
Ry[B] : rotation of optic axis in zenith angle;
Rz[a] : rotation of optic axis in azimuth;

and the composite rotation:

$$R[a,B,g] = Rz[a]Ry[B]Rz[g]$$

This composite matrix allows us to convert from camera (ASI) coordinates to local, fixed (topocentric) coordinates using:

$$P(fixed) = R[a,B,g]P(asi),$$

where P(asi) are the Cartesian coordinates of the position of an object in an ASI image.

The ASI geometric alignment data are provided as part of the annual calibration exercise. The data included are:

co = column intersected by optic axis
ro = row intersecting optic axis
k1 = linear coefficient of radial compression correction
k2 = quadratic coefficient of radial compression correction
and angular components alpha, beta, and gamma.

These elements allow us to convert the location of any pixel in an ASI image to Cartesian coordinates of the local (Gillam) topocentric system. To convert from ASI image position (col,row) to ASI Cartesian coordinates:

```
   dx = col - co

   dy = row - ro

    r = (sqrt( dx^2 + dy^2 )

theta = k1*r + k2*r^2

  phi = arctan ( dy/dx )
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and

```
    x = sin(theta)cos(phi)

    y = sin(theta)sin(phi)

    z = cos(theta)
```

which are the ASI position vector P(asi). This process ends with P(fixed), the Cartesian coordinates of the object, in the local topocentric coordinate system. This can then be converted to any desired system.

3. Calibration History

The calibration records for ASI data go back to the first installation at Gillam in October, 1986. However, only the calibration factors relating to ASI in "high-resolution operation mode (since 1992) are considered here.

Each year in the Spring, the ASI is retrieved from the field, refurbished, and calibrated, It is then re-installed at Gillam in the Fall. The operating period from the Fall re-installation to the subsequent Spring retrieval defines the calibration "epoch". For each calibration epoch, there exists a full set of calibration data, which includes:

"R" values
Filter peak wavelengths and passband curves *
"Q" array
"P" array
co,ro; position of optic axis
k1,k2; radial correction
a,B,g; alignment rotation angles.

* the information derived from the filter curves is included in the "R" values.

Thus, when processing ASI data, it is necessary to take the date of the ASI image data into account, and use it to select the set of calibration factors

appropriate to the given epoch.

The ASI calibration epochs, since 1992 are:

Epoch Name	Start of Epoch	End of Epoch	Reason	Cal'n Data Set
1992	Sept. 18, 1992	December 6, 1992	(replace CCD)	cgy9209, gil9209
????	December 7, 1992	April 28, 1993	(retrieval)	gil9212
1993	October 15, 1993	May 27, 1994	(sun shield)	cgy9309, gil9310
1994	September 1, 1994	May 7, 1995	(turn off)	cgy9408, gil9408
1995	October 18, 1995	May 22, 1996	(sun shield)	cgy9509, gil9510

Alignment Data Summary

Year	co	ro	k1	k2	a	B	g	a+g
1992	125.9	127.3	n/a	n/a	n/a	0.4	n/a	5.8
1993	129.2	127.7	n/a	n/a	n/a	0.5	n/a	6.6
1994	121.8	130.1	0.624	8.28E-04	148.26	0.53	-141.79	6.5
1995	125	129	0.624	8.28E-04	137.82	0.00	-137.60	0.22

Responsivity Summary

Year	R5577	R6300	R4278	R7370	R6075
1992	0.0616	0.0676	0.0177	0.0282	n/a
1993	0.1013	0.1120	0.0282	0.0557	n/a
1994	0.1106	0.1222	0.0299	n/a	0.1149
1995	0.081	0.062	0.0084	n/a	0.063