MIT Kavli Institute **Chandra X-Ray Center**

MEMORANDUM
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To:	Jonathan McDowell, SDS Group Leader
From:	Glenn E. Allen, SDS
Subject:	Sub-pixel event-positioning spec
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1 Sub-pixel event positioning

1.1 Description

The size of the point spread function of a point source observed with the ACIS detectors is determined by several factors: (1) the size of the point spread function of the mirrors, (2) the accuracy to which the pointing direction can be reconstructed, (3) the size of the pixels on the ACIS CCDs, and (4) "pixel randomization." The randomization is performed by adding a uniform random deviate in the range from −0.5 to +0.5 adu to the chip coordinates `CHIPX` and `CHIPY` when the detector coordinates `DETX` and `DETY` are calculated. This randomization is propagated to the sky coordinates `X` and `Y`. Pixel randomization was introduced to avoid aliasing effects that can produce unusual features in the shape of the image of a point source for some observations. **The randomization is automatically disabled if the sub-pixel event-positioning algorithm is used.**

The size of an ACIS pixel undersamples the point spread function of an on-axis point source. As a result, the use of the ACIS detectors can degrade the quality of an image of a source, particularly if events are assumed to occur at the centers of the pixels for which they are reported. Tsunemi et al. (2001), Mori et al. (2001), Li et al. (2003), and Li et al. (2004) describe algorithms that can be used to more accurately locate the centroids of certain events based upon the distribution of charge in the "event islands.[1]"

This spec describes the implementation of the energy-dependent sub-pixel event-positioning algorithm ("EDSER") of Li et al. (2004) in the tool `acis_process_events`. This algorithm is the one that works best for GRADED and non-GRADED mode event data.

1.2 Input

1. A Level 1 or 2 event-data file (acis*evt1.fits, acis*evt1a.fits, acis*evt2.fits)
2. A sub-pixel ARD file (acisD*subpix*.fits)

[1] An event island, the quantity named `PHAS` in a Level 1 event-data file, contains the pulse-height distribution in a 3 pixel × 3 pixel region centered upon the pixel in which an event is reported. In `VFAINT` mode, `PHAS` is a 5×5 array instead of a 3×3. The `PHAS` information is not telemetered for `GRADED` mode data. However, the `FLTGRADE`, a scalar representation of the distribution of charge in the central 3×3, is telemetered for both `GRADED` and non-`GRADED` modes. Only one of sub-pixel event-positioning algorithms requires `PHAS` (i.e. the algorithm "CSDSER" of Li et al. 2004). All of the rest use `FLTGRADE`.

1.3 Output

1. An event-data file in which the coordinates `DETX` and `DETY` and, perhaps, `X` and `Y` have been updated. Note that the coordinates `CHIPX`, `CHIPY`, `TDETX`, and `TDETY` are not modified.

1.4 Parameters

1. `infile,s,a,"",,,"Name of input event-data file"`

2. `outfile,s,a"",,,"Name of output bad-pixel file"`

3. `subpixfile,s,h,"CALDB",,,"Name of input sub-pixel file (CALDB | NONE | none | <filename>)"`

4. `pix_adj,s,h,"edser",,,"Sub-pixel adjustment algorithm (edser | none | randomize)"`

1.5 Processing

Perform the following tests before processing begins.

- Verify that the `infile` and `subpixfile` exist. If they do not, then exit with an error message.

- If `clobber = no`, then verify that the `outfile` does not exist. If it does, then exit with an error message.

- If `pix_adj = edser`, then verify that `DATAMODE = FAINT`, `FAINT_BIAS`, `GRADED`, or `VFAINT`. If it does not (e.g. if `DATAMODE = CC_FAINT` or `CC_GRADED`), then exit with an error message. **Other modes?**

- If `pix_adj = edser`, then verify that `stop = det`, `tan`, or `sky`. If it does not, then exit with an error message.

If `pix_adj = none`, then do not use either the sub-pixel event-positioning algorithm or the pixel randomization algorithm.

If `pix_adj = randomize`, then apply the pixel randomization algorithm, where **the range of the uniform random deviate is specified by the parameter `rand_pix_size`.** Do not use the sub-pixel algorithm.

If `pix_adj = edser`, then use the sub-pixel algorithm described below. Do not apply the pixel randomization. The sub-pixel event-positioning algorithm should be performed after the `ENERGY` and `FLTGRADE` have been computed since the algorithm depends upon these quantities. The calculation should occur before the detector coordinates `DETX` and `DETY` are calculated since these coordinates depend upon the results of the sub-pixel positioning. If the sky coordinates `X` and `Y` are calculated, then the calculation should use the updated values of `DETX` and `DETY`.

Perform the following steps, in sequence, for each event.

1. Use the value of `CCD_ID` to select the appropriate HDU in the sub-pixel ARD file and use the value of `FLTGRADE` to select the appropriate row in that HDU (see sec. 2).

2. Use the expressions

$$\mathtt{CHIPX}' = \mathtt{CHIPX} + (\Delta X_{i+1} - \Delta X_i)\left(\frac{E - E_i}{E_{i+1} - E_i}\right) + \Delta X_i \quad (1)$$

and

$$\mathtt{CHIPY}' = \mathtt{CHIPY} + (\Delta Y_{i+1} - \Delta Y_i)\left(\frac{E - E_i}{E_{i+1} - E_i}\right) + \Delta Y_i \quad (2)$$

to calculate the real-valued, sub-pixel locations of CHIPX′ and CHIPY′, respectively.[2] Here E is the ENERGY of the event and

$$\begin{aligned} E_i &= \texttt{ENERGY}_i, & (3)\\ E_{i+1} &= \texttt{ENERGY}_{i+1}, & (4)\\ \Delta X_i &= \texttt{CHIPX\_OFFSET}_i, & (5)\\ \Delta X_{i+1} &= \texttt{CHIPX\_OFFSET}_{i+1}, & (6)\\ \Delta Y_i &= \texttt{CHIPY\_OFFSET}_i, \text{ and} & (7)\\ \Delta Y_{i+1} &= \texttt{CHIPY\_OFFSET}_{i+1}, & (8) \end{aligned}$$

where the quantities on the right-hand sides of equations 3–8 are from vectors in the ARD file (see sec. 2).

The values of i and $i+1$ are the ones that satisfy the relationship

$$E_i \leq E < E_{i+1}. \tag{9}$$

The valid ranges for i and $i+1$ are from 0 to $\texttt{NPOINTS} - 2$ and from 1 to $\texttt{NPOINTS} - 1$, respectively.[3] If $E > E_{\texttt{NPOINTS}-1}$, then use $i = \texttt{NPOINTS} - 2$ and $i + 1 = \texttt{NPOINTS} - 1$ (i.e. extrapolate instead of interpolate). Since E should always be greater than zero and since $E_0 = 0$, in no case shall $i < 0$.

3. Use the values of CHIPX′ and CHIPY′ to calculate the detector coordinates DETX and DETY and, depending on the value of the parameter `stop`, the sky coordinates X and Y.

4. If the parameter `eventdef` includes `f:chipx_adj` and/or `f:chipy_adj`, then write the coordinates CHIPX′ and/or CHIPY′ to the `outfile`.[4]

5. Create or update the header keyword PIX_ADJ in the `outfile`. This keyword should have the same value as the parameter `pix_adj`.

6. Create or update the header keyword RAND_SKY in the `outfile`. If `pix_adj = edser`, then set RAND_SKY = 0. If `pix_adj = none` and `stop = none`, `chip`, or `tdet`, then copy the value of RAND_SKY from the `infile` to the `outfile`. If the keyword does not exist in the `infile`, then set RAND_SKY = 0. If `pix_adj = none` and `stop = det`, `sky`, or `tan`, then set RAND_SKY = 0. If `pix_adj = randomize`, then set RAND_SKY equal to the value of the parameter `rand_pix_size`.

1.6 Caveats

1. This sub-pixel event-positioning algorithm cannot produce a point spread function that is better than the point spread function produced by the mirrors and by the accuracy of the reconstruction of the pointing direction of the telescope. It is not a deconvolution algorithm.

2. At this time, the effects of this sub-pixel algorithm on the point spread function of an astrophysical source are not calibrated.

3. The use of a sub-pixel event-positioning algorithm can influence the fraction of the events inside a source extraction region. At present, this effect is not included in the response tools.

2 Sub-pixel positioning ARD

The sub-pixel event-positioning algorithm requires input that is specified in an ARD file. Aside from a null primary header, the ARD file includes ten separate HDUs (one HDU for each CCD). Each HDU contains one binary table with the following columns.

[2] In no case does $|\texttt{CHIPX}' - \texttt{CHIPX}|$ or $|\texttt{CHIPY}' - \texttt{CHIPY}|$ exceed 0.5 pixels.

[3] NPOINTS is the name of a column in the ARD file (see sec. 2).

[4] The data in the columns `chipx_adj` and `chipy_adj` will be valuable for testing purposes and may be of interest to some users.

- FLTGRADE
- NPOINTS
- ENERGY
- CHIPX_OFFSET
- CHIPY_OFFSET

There is one row for each FLTGRADE. The columns ENERGY, CHIPX_OFFSET, and CHIPY_OFFSET contain vectors for each row. These vectors are used to perform the linear interpolation and extrapolation described in section 1.5. Only the first NPOINTS elements in the vectors should be used for this process. The remaining elements, if any, contain zeroes. The information in the ARD file is based on the data in Figure 4 of Li et al. (2004).

3 TBD

- Should this sub-pixel event-positioning algorithm be applied to the spatial and temporal coordinates of continuous-clocking mode data?
- Should this sub-pixel algorithm be incorporated into the tool tg_resolve_events?

References

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