epicbscalgen

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Abstract

Optimization of boresight misalignment angles from observation data for EPIC

1 Instruments/Modes

Instrument	Mode
EMOS1/EMOS2	n/a
EPN	n/a

2 Use

pipeline processing	no
interactive analysis	no
CCF maintenance	yes

3 Description

The XMM Current Calibration File contains the constituent `CCF::Boresight` [1] which holds for each instrument a tuple of three angles (ϕ, θ, ψ) describing the misalignment of the respective instrument boresight with respect to the satellite coordinate frame (SACCOORD – see documentation of package **cal**. The angles are to be interpreted as 3-2-1 Euler rotation angles[2] through which the SACCOORD frame is transformed into the instrument boresight (IBS) frame as depicted in Fig. 1 for the case of EMOS2. Formally, the IBS is defined as follows:

- The $+X$ axis points along the optical axis of the telescope of the respective instrument from the focal plane into the sky.
- The $+Z$ axis is orthogonal to the $+X$ axis and lies in the plane spanned by the $+X$ axis and the $+Z$ axis of the CAMCOORD2 (see documentation of package **cal** frame.
- The $+Y$ axis completes the right-handed, orthonormal Cartesian coordinate frame.

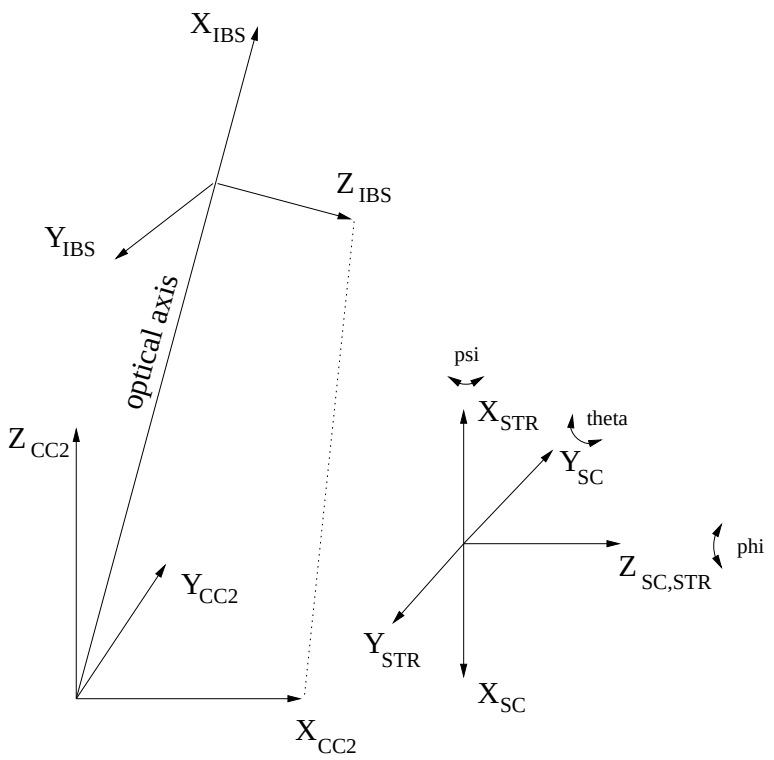

Figure 1: Coordinate frames used in **epicbscalgen**

The computation of the angles is a purely geometrical problem and, thus, should have a straightforward analytical solution. However, due to the large number of involved independent variables (Ra/Dec of pointing, position angle, position of cameras in satellite frame, uncertainties in focal lengths, position and extent of sources being looked at, etc.) and the fact that math with Euler angles is non-trivial **epicbscalgen** employs an empirical scheme which is outlined below. The scheme has the following advantages:

- The process is fully automatic in the sense that is does require only minimal input from the person running the task.
- It is bound to always give the right answer (chances of making mistakes are small).
- The correctness of the algorithm can be tested with SciSim.

3.1 Computational scheme

3.1.1 Input

The scheme has two main inputs:

- A calibrated event list (at least with the sky pixel columns `X`/`Y` as produced by the corresponding SAS tasks **emproc**/**epproc** for MOS and PN respectively. The image generated from this event list must contain at least two distinct sources which the SAS **eboxdetect** can detect.

- The true (cataloged) positions $(\alpha_i^{\rm ref}, \delta_i^{\rm ref})$, $i = 1, \ldots, N$ for a number $N \geq 2$ of sources in the image generated from the event list.

3.1.2 Output

The task generates a unique set of 3-2-1 Euler angles (ϕ, θ, ψ) to be put in the CCF constituent `Boresight`.

3.1.3 Algorithm

The basic idea is to minimize the difference between the true source coordinates and the ones computed by the **eboxdetect** as a function of the three angles. More explicitly, the following steps are carried out:

1. $n = 0$
2. Set $(\phi_0, \theta_0, \psi_0) = (0, 0, 0)$, i.e. assume perfect alignment between the star tracker/spacecraft and instrument boresight frame in Fig. 1.
3. run the task **attcalc** on the event list EL_{n-1} producing a new event list EL_n with sky coordinates corresponding to the tuple $(\phi_n, \theta_n, \psi_n)$.
4. accumulate a sky image IMG_n from event list EL_n with task **evselect**
5. run **eboxdetect** on IMG_n which gives a list of source positions in absolute sky coordinates $(\alpha_i, \delta_i)_n$, $i = 1, \ldots, N$
6. identify the reference sources in the new source list and compute

$$\epsilon_n = \sum_{i=1}^{N} (\alpha_i^{\rm ref} - \alpha_i)^2 + (\delta_i^{\rm ref} - \delta_i)^2 \tag{1}$$

7. if ϵ_n is small enough the sought set of angles is found:

$$(\phi_n, \theta_n, \psi_n) \tag{2}$$

   else

   - compute new angles for the next iteration

$$\begin{aligned} n &= n + 1 \\ \phi_n &= \phi_{n-1} + \Delta\phi_n \\ \theta_n &= \theta_{n-1} + \Delta\theta_n \\ \psi_n &= \psi_{n-1} + \Delta\psi_n \end{aligned}$$

   - set boresight angles to $(\phi_n, \theta_n, \psi_n)$ via the CAL
   - goto 3

   endif

Thus, the procedure is a minimization of the sum of squares of the absolute deviations of the reference source positions from the true values in the 3-dimensional parameter space of the boresight misalignment angles. The actual minimization scheme employed is the Nelder-Mead Simplex method[3] which uses only function evaluations. It has been found that the Simplex scheme is much better suited than conventional conjugate gradient methods which often fail to efficiently find the direction to the global minimum. The

dependency of ϵ on the third angle ψ, i.e., the calibration around the optical axis, has been found to be fairly weak. For the sake of efficiency, the search for the global minimum has therefore been split into two stages:

1. Minimization of $\epsilon = \epsilon(\phi, \theta, \psi = \text{const})$ with a fairly relaxed stopping criterion.
2. Starting from the local minimum found in step 1, full minimization of $\epsilon = \epsilon(\phi, \theta, \psi)$ with a more stringent stopping criterion.

3.2 Practical examples and hints

The usage of the task is very straightforward and the possibilities of making mistakes are small. The following points should be noted however:

- **epicbscalgen** is a meta-task that makes use of a couple of other SAS tasks, viz.:
  - **evselect**
  - **attcalc**
  - **eboxdetect**
  - **srcdisplay**
  - **imgdisplay**

  A basic familiarity with the functionality provided by these tasks is recommended. This is not a pre-requisite of making use of **epicbscalgen** though.
- It is recommended to run the task on a verbosity level 5 for getting a feeling for the operations carried out in each iteration.
- For controlling the convergence process it is usually advantageous to re-direct the standard output and error stream into a file and monitor its contents. This can be done with

  ```
  unix> epicbscalgen -V 5 eventtable=ev.ds 2>&1 | tee log
  ```

  (`sh` syntax) which duplicates the standard error and output stream and logs all output in the file `log`. While the task is running the convergence process can then be monitored by periodically checking the content of `log` for the actual values of ϵ and the angles (ϕ, θ, ψ):

  ```
  unix> fgrep 'Iteration' log
  unix> fgrep 'New set of Euler angles' log
  ```

  With each iteration, ϵ should get smaller and the Euler angle tuple should approach the sought solution.
- In the very first iteration, the user is required to input the true coordinates of at least two sources interactively. For this Ds9 is launched showing an image that has been accumulated from the input event list with all found sources marked through *excluded circles*. For each source that is to be used as a reference source the user needs to:
  1. Double click with the left mouse button on the respective circle marker.
  2. In the dialog box that will pop up:
     (a) Select the menu item "Properties" $\longrightarrow$ "Include/Exclude". After that the circle marker will be redrawn with a solid line which marks the source as a reference source.

(b) In the field "Text", input the celestial J2000 coordinates (right ascension/declination) of the source in the form

```
23h59m48.12s / 45o38'14.55"
```

or

```
123.23445 / 45.238474
```

3. Click on "Apply" and "Close"

If done, hit the `Enter` key in the terminal window from which the task was started. If all input is ok, execution shall proceed normally, otherwise an error message should be produced.

There is an alternative reference source input method available that is activated with the `withrefsrclist` parameter. Here an **eboxdetect**-compliant source list data set is required from which the true celestial coordinates will be obtained. As in the scheme described above in a first iteration a source detection will be performed on the image from the given event list and the result displayed using Ds9. Then, the given reference source list is read and likewise displayed on the image however with a different color and the markers labeled with the respective source indices. The user is now requested to perform the cross-correlation between the two source marker sets by activating, i.e. *including*, the corresponding markers from the source detection run and labeling them with the right indices. Detailed on-screen instructions on this are given when this input scheme is selected.

- Convergence to the minimum can be slow - in this regard it is worth noticing that the Nelder-Mead-Simplex method is not optimized for minimum number of function evaluations. Please monitor the convergence process in the above described manner. As long as ϵ is steadily decreasing there is no need for any intervention.
- If two or more of the selected reference sources do not differ in flux by more than 5% it is conceivable that possible source-confusion problems are reported. This is not a real problem as long as the affected sources are sufficiently spatially separated from each other such that the scheme can uniquely identify them in each iteration. A failure to do so would typically lead to an oscillating ϵ. In this case, please stop the task and re-start with different reference sources. Choosing a different source radius (see parameter `sourceradius`) may also help to resolve the problem.
- The above described scheme is rather CPU intensive because it involves the execution of several non-trivial tasks. The main performance driver is clearly the size of the initial event list which should be kept as small as possible.

4 Parameters

This section documents the parameters recognized by this task (if any).

Parameter	Mand	Type	Default	Constraints
eventtable	yes	table		Name of existing EPIC event list

The input event table which drives the boresight angle optimization. It must contain sky image coordinates computed by **attcalc**; it is likely to be the primary output event list from the chain processing tasks **emproc** or **epproc**.

xcolumn	no	column	X	name of existing column in table `eventtable`

The name of the column in the input event table containing X-coordinates of sky pixels (used to accumulate sky image with **evselect**)

ycolumn	no	column	Y	name of existing column in table `eventtable`

The name of the column in the input event table containing Y-coordinates of sky pixels (used to accumulate sky image with **evselect**)

binx	no	integer	50	$1 \leq$ `binx` ≤ 200

size of sky image pixel bin in X-direction (used to accumulate sky image with **evselect**) - please note: values less than 20 will lead to very large sky images and corresponding performance degradations

biny	no	integer	50	$1 \leq$ `biny` ≤ 200

size of sky image pixel bin in Y-direction (used to accumulate sky image with **evselect**) - please note: values less than 20 will lead to very large sky images and corresponding performance degradations

nruns	no	integer	1	$1 \leq$ `nruns` ≤ 4

Duplicates corresponding parameter of task **eboxdetect**; controls the source detection process; for more information please consult description of task **eboxdetect**.

likemin	no	real	15	$1 \leq$ `likemin` ≤ 20

Duplicates corresponding parameter of task **eboxdetect**; controls the source detection process; for more information please consult description of task **eboxdetect**.

sourceradius	no	real	.01	$0.0001 \leq$ `sourceradius` ≤ 2

Radius in degrees of circle that will be drawn around each detected source.

runshowdetect	no	boolean	true	false|true

Boolean switch determining whether or not to show the result of the **eboxdetect** run in each iteration.

withrefsrclist	no	boolean	false	false|true

Boolean parameter controlling the source reference input method. When set to `false` the celestial coordinates of the reference sources have to be typed in explicitly, otherwise they are taken from the source list data set in `refsrclist`.

refsrclist	no	data set		name of existing source list

If `withrefsrclist` is set to `true` the parameter contains the name of an **eboxdetect**-compliant source list from which the true celestial coordinates of the reference sources are to be read. Actually, from all the columns in an **eboxdetect** source list only `RA` and `DEC` shall be used, i.e., the others can be omitted. The source table row number is used as the source index starting from 1.

phi	no	real	0	$-3600 \leq \phi \leq +3600$

Starting value of the boresight misalignment angle $180° - \phi$ (see Figure 1) in arcsecs.

theta	no	real	0	$-3600 \leq \phi \leq +3600$

Starting value of the boresight misalignment angle θ (see Figure 1) in arcsecs.

psi	no	real	0	$-3 \leq \psi \leq +3$

Starting value of the boresight misalignment angle ψ (see Figure 1) in degrees.

tol1	no	real	1.e-1	$10^{-10} \leq$ `tol1` $\leq 10^{-1}$

The parameter controls the stopping criterion for the stage-I minimization as described above. The scheme stops if the fractional convergence tolerance in the function value ϵ is lower than the given value. Please note: The default value is quite large because the stage-I minimization is only intended to yield approximately correct value for ϕ and θ for a given fixed ψ.

tol2	no	real	1.e-4	$10^{-10} \leq$ `tol1` $\leq 10^{-1}$

The parameter controls the stopping criterion for the stage-II minimization as described above. The scheme stops if the fractional convergence tolerance in the function value ϵ is lower than the given value. Please note: This value is smaller than the corresponding one for stage I because is determines the quality of the final set of angles.

maxiter	no	integer	1000	$0 \leq$ `maxiter` ≤ 1000

Maximum allowed number of iterations in stage I + stage II to find a unique solution.

5 Errors

This section documents warnings and errors generated by this task (if any). Note that warnings and errors can also be generated in the SAS infrastructure libraries, in which case they would not be documented here. Refer to the index of all errors and warnings available in the HTML version of the SAS documentation.

NoSourcesFound *(error)*
The **eboxdetect** task failed to find any sources in the image accumulated from the input event list. This is a very unlikely scenario. If it arises, something is fundamentally wrong with the input event table.

WrongSourceCoordinates *(error)*
The reference source coordinates are given in a wrong/unrecognized format - see above for the correct one.

NoSourceCoordinates *(error)*
No coordinates have been given for a selected reference source.

TooLittleSources *(error)*
Less than two reference sources have been selected. The above schemes needs at least two because there are three degrees of freedom.

NumericalError *(error)*
There has been a numerical error - this should not happen.

SourceMismatch *(error)*
The source detection procedure has failed to uniquely find the user-selected reference source in a newly accumulated image. Try to increase the source radius.

maxiterationsReached *(error)*
The maximum number of iterations have been performed without achieving convergence - this is a very unlikely situation.

(error)
All errors of **evselect**, **eboxdetect**, **attcalc**.

NegativeSourceCounts *(warning)*
The **eboxdetect** task has computed a negative flux for a found source - this should not happen.
corrective action: ignore source

PossibleSourceConfusion *(warning)*
The task has failed to uniquely identify the user-selected reference sources in a newly accumulated image. The source cross-identification is based on a simple integrated flux criterion which is known to be deficient. There is no real problem as long as the sources in question are sufficiently spatially separated. If this is not the case, the algorithm will not abort execution but the user should see an oscillating behavior in ϵ.
corrective action: ignore

(error)
All warnings of **evselect**, **eboxdetect**, **attcalc**.

6 Input Files

1. An event list file with sky coordinates (as produced by **emproc** or **epproc** for EMOS1, EMOS2, or EPN.

7 Output Files

1. none - upon successful exit the task prints the found boresight misalignment angles to `stdout`.

8 Algorithm

see above

9 Comments

- Although the task works on EPIC data only it should also be applicable to OM.

10 Future developments

- Make it work on OM data as well.

References

[1] ESA. Interface control document for the XMM current calibration file. Technical Report XMM-GEN-ICD-0005, ESA/SSD, Dec 2001. Issue 4.0.

[2] J.R. Wertz, editor. *Spacecraft Attitude Determination and Control.* Reidel Publishing Comp, London, 1978.

[3] W.T. Vetterling W.H. Press, S.A. Teukolsky and B.P. Flannery. *Numerical Recipes in C.* Cambridge University Press, New York, 1992.