Pointing Transfer and the MIPS Scan Mirror

F. J. Masci , 11/21/2002

This document outlines a method for transforming the pointing/twist angle in the TPF (Telescope Pointing Frame – i.e. boresight) to any MIPS IPF (Instrument Pointing Frame) by allowing for arbitrary rotations of the scan mirror. It is based on a combination of algorithms presented in J. W. Fowler's working notes (JWF): "Pointing Transfer Subsystem" (May 5, 1999) and D. S. Bayard's/T. Kia's Engineering Memorandum (DSB): "EM 3455-01, Aug. 20, 2001". The method below does not handle uncertainties associated with scan-mirror rotation (TBR). In section (III) I suggest a method to tie the formalism to existing software.

I. Overview

The transformation sequence from celestial coordinates (RA, DEC, TWIST = α_S, δ_S, γ_S) to the TPF, to sky coordinates in the IPF (α_I, δ_I, γ_I) allowing for arbitrary rotations (θ) of the scan mirror about its axis can be written:

$$\mathrm{SKY}(\alpha_S, \delta_S, \gamma_S) \xrightarrow[1]{} \mathrm{TPF} \xrightarrow[2]{} \mathrm{IPF}_{\theta=0}(\alpha_I, \delta_I, \gamma_I) \xrightarrow[3]{} \mathrm{IPF}_{\theta\neq 0}(\alpha_I, \delta_I, \gamma_I)$$

Transformations 1, 2, 3 are independent and can be represented by matrices defined as follows. See the references for more details.

<u>Transformation 1</u>: Let us define this as T_C^B . This involves an Euler rotation sequence to transform from celestial coordinates to an XYZ system of the spacecraft's TPF. See JWF working notes (pg. 3). The matrix elements are functions of celestial coordinates.

<u>Transformation 2</u>: Let us define this as T_B^I . This involves a second Euler rotation sequence to transform from the TPF to a "fixed" instrument array (IPF). See JWF working notes (pg. 4). The matrix elements are functions of boresight-instrument offset angles, to be derived from the focal plane survey. As it stands, transformations 1 and 2 can be seen as a conversion from celestial coordinates to the IPF where the scan mirror has no affect on the optical light path. We shall denote this by a mirror rotation which is effectively "zero".

<u>Transformation 3</u>: Let us define this as T_I^θ . This is a <u>new matrix</u> whose elements are functions of the mirror rotation angle about its axis. This transforms from our nominal IPF($\theta = 0$) (where the mirror plays no role) to an IPF where the rotation $\theta \neq 0$. From DSB's working notes (pg. 10), this matrix is parametrized as follows:

$$T_I^\theta = \cos(\beta\theta).I + [1 - \cos(\beta\theta)].a_m a_m^{\;T} - \sin(\beta\theta).a_m^{\;\times}$$

where:

θ = Measured scan mirror angle about its axis such that $T_I^{q=0} = I$ (3 × 3 identity matrix).
β = Scale factor associated with measured mirror angle.

$a_m = \begin{bmatrix} a_{m1} \\ a_{m2} \\ a_{m3} \end{bmatrix}$ (Scan mirror axis represented as a 3 × 1 unit vector whose components must satisfy: $\sum_{n=1}^{3} a_{mn}^2 = 1$

$a_m{}^T = [a_{m1}, a_{m2}, a_{m3}]$ (Transpose of a_m)

$$a_m{}^{\times} = \begin{bmatrix} 0 & -a_{m3} & a_{m2} \\ a_{m3} & 0 & -a_{m1} \\ -a_{m2} & a_{m1} & 0 \end{bmatrix} \text{ (Cross-product matrix)}$$

The product $a_m\, a_m{}^T$ which appears in the matrix equation for transformation 3 (T_I^q) can be expanded as:

$$a_m a_m{}^T = \begin{bmatrix} a_{m1}^2 & a_{m1}a_{m2} & a_{m1}a_{m3} \\ a_{m2}a_{m1} & a_{m2}^2 & a_{m2}a_{m3} \\ a_{m3}a_{m1} & a_{m3}a_{m2} & a_{m3}^2 \end{bmatrix}$$

The product of the three matrices defining transformations 1, 2 and 3 (in the correct order) will yield a matrix giving the "total" transformation from sky coordinates to "effective" instrument array defined by an arbitrary rotation of the scan mirror:

$$T^q{}_C = T^q{}_I\, T^I{}_B\, T^B{}_C$$

When the angle of the mirror is such that θ = 0 in the above notation, the solution reduces to the normal case where there is no scan mirror (eg. IRAC and IRS).

Following the procedure in JWF's working notes (pg. 4), the final pointing solution in the IPF(θ ≠ 0) array can be computed from the matrix elements of T_C^q .

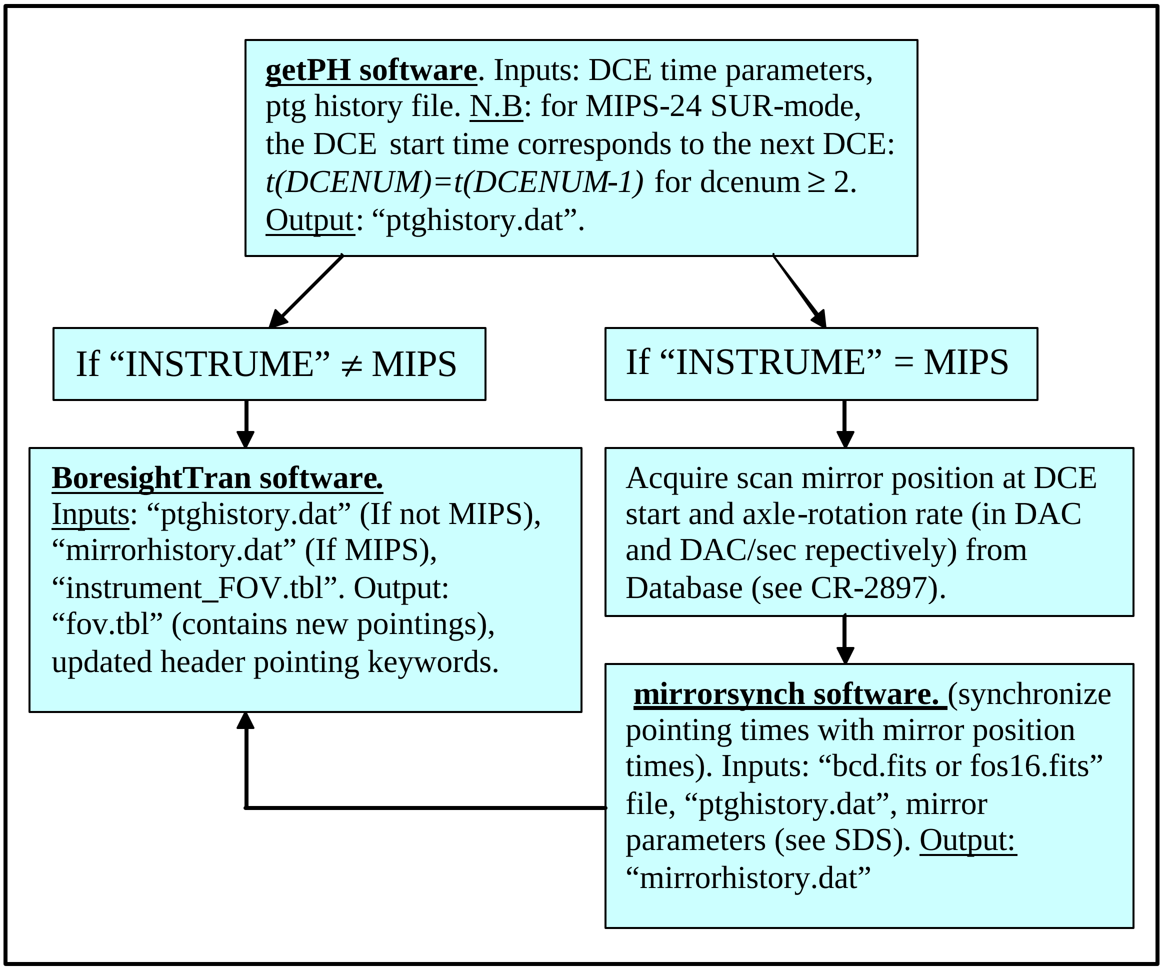
II. Input (Calibrated) FOV parameters for MIPS

The above formalism will require ten instrument parameters defining the position of an array's FOV with respect to the boresight. Four of these are new and correspond to the scan mirror. All these will be provided by the focal plane survey as described in DSB:

- Instrument angle offsets and variances (in JWF's notation): θ_1, θ_2, γ_I, V_{YI}, V_{ZI}, V_{ZI}
- Mirror parameters (in DSB's notation; see above): $a_{m1}, a_{m2}, a_{m3}, b$.

III. Suggested Implementation

1. F. Masci will generate a Mirror Pointing History File (MPHF) by synchronizing pointings from the Boresight Pointing History File (BPHF) over the time-span of a DCE with scan-mirror positions (θ) queried from the database. F. Masci will update output from the "getPH" software (i.e. the ptghistory.dat file) and append to it an additional column representing the scan-mirror angle at the pointing-sampling times. Let us call the resulting file "mirrorhistory.dat".
2. In the boresight transfer pipeline thread, the MPHF will only be generated if we are dealing with a MIPS DCE (i.e. with header keyword INSRUME = "MIPS"). Otherwise, the BPHF will only be used downstream (in the "boresightTran" software). See the flowchart below.
3. J. Li will be required to make the following modifications to "boresightTran": (i) Multiply the current transformation by the T_I^q matrix defined above and read in an updated instrument FOV parameter file (containing mirror parameters). (ii) The software will therefore become as general as possible: If the image header keyword INSRUME = "MIPS", read in the "mirrorhistory.dat" file containing θ and corresponding boresight pointings. Please note that θ is in degrees and will need to be converted into radians in the computation steps. If INSRUME ≠ "MIPS", set θ = 0 for all pointing-history times, read in the ptghistory.dat file as before and proceed as normal.


getPH software. Inputs: DCE time parameters, ptg history file. N.B: for MIPS-24 SUR-mode, the DCE start time corresponds to the next DCE: t(DCENUM)=t(DCENUM-1) for dcenum ≥ 2. Output: “ptghistory.dat”.
If “INSTRUME” ≠ MIPS
If “INSTRUME” = MIPS
BoresightTran software. Inputs: “ptghistory.dat” (If not MIPS), “mirrorhistory.dat” (If MIPS), “instrument_FOV.tbl”. Output: “fov.tbl” (contains new pointings), updated header pointing keywords.
Acquire scan mirror position at DCE start and axle-rotation rate (in DAC and DAC/sec repectively) from Database (see CR-2897).
mirrorsynch software. (synchronize pointing times with mirror position times). Inputs: “bcd.fits or fos16.fits” file, “ptghistory.dat”, mirror parameters (see SDS). Output: “mirrorhistory.dat”