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ASC Coordinate Transformation—The Pixlib Library

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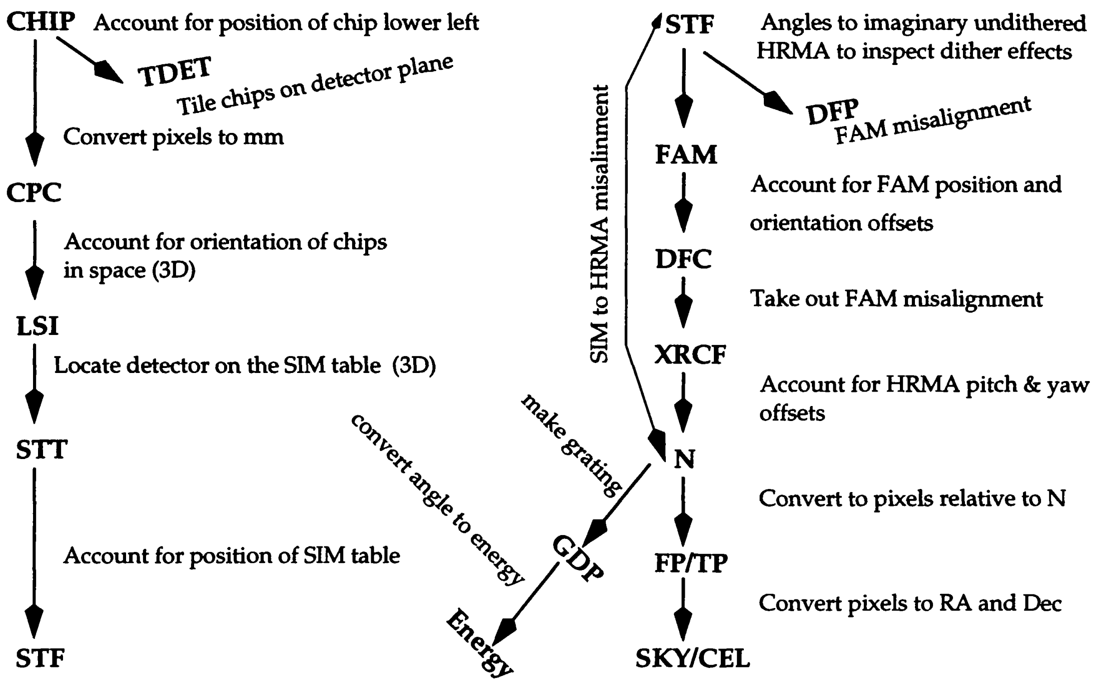
Abstract. We describe a coordinate library for *AXAF* data analysis. The library handles transformations between celestial coordinates and instrumental (mirror, focal plane, detector pixel) coordinate systems. The need for careful transformations is driven by the accuracy of the detectors and the attitude determination system. The coordinate systems are characterized by parameter files generated from experimental and calibration data. Transformation calculations are performed by matrix-representation routines for maximum flexibility. This library is implemented in ANSI C, and uses the SAO IRAF-compatible parameter interface.

1. Introduction

Pixlib library is intended to perform *AXAF* Science Center (ASC) coordinate system data analysis. The library facilitates space telescope simulations dealing with five science instruments (SI) or detectors (e.g., ACIS, HRC-I), each constructed up to ten chips. The pixlib is designed to be a structured system, to promote system extensibility and maintainability. The fundamentals of the program are provided by a number of modules which rely on external parameter interface files. The parameter files determine the essential characteristics of the ASC coordinate systems. The coordinate transformation computation utilizes matrix arithmetic algorithms for coding efficiency and software reusability. The integrated library provides a comprehensive collection of functions for user applications, and these functions are well documented, easy to use, and FORTRAN-binding compatible. At the present, the library affords more than 50 transformations among ~20 ASC coordinate systems.

2. System Design

Figure 1 lists the most important ASC coordinate systems and sketches the transformation paths among them. Items threaded by line arrows denote coordinate systems, e.g., **CHIP** for 2-D chip pixel coordinates, **CPC** 2-D chip physical coordinates in mm, **TDET** 2-D tiled detector plane pixel coordinates, and **LSI** for local SI coordinates. The line arrows connecting a pair of coordinate systems indicate the coordinate transformation is both forward and backward, and the aim of the transformation is explained at the side. For instance, transformation of **CPC** to **LSI** is to account for chip orientation in space, and **N** to **FP** is to convert the 3-D HRMA nodal position to the 2-D pixel focal plane co-



CHIP
Account for position of chip lower left
TDET
Tile chips on detector plane
Convert pixels to mm
CPC
Account for orientation of chips in space (3D)
LSI
Locate detector on the SIM table (3D)
STT
Account for position of SIM table
STF
convert angle to energy
make grating
GDP
Energy
SIM to HRMA misalinment
STF
Angles to imaginary undithered HRMA to inspect dither effects
DFP
FAM misalignment
FAM
Account for FAM position and orientation offsets
DFC
Take out FAM misalignment
XRCF
Account for HRMA pitch & yaw offsets
N
Convert to pixels relative to N
FP/TP
Convert pixels to RA and Dec
SKY/CEL

Figure 1. ASC coordinate systems and the transformations.

ordinates. Details on the definitions and determinations of the ASC coordinate systems are discussed in a memo (McDowell 1996).

The goal of pixlib is to build up a software framework for the coordinate systems outlined above, and provide functions to perform the coordinate transformations between any two systems. Borrowing from the C++ class concept, the pixlib distinguishes "private" (lower-level) data/functions and "public" (upper-level) routines. The private section, composed of more than five independent modules, is constructed on a set of external parameter files that hold the definitions and aspects of the ASC coordinate systems (to be discussed in next section). A struct member is defined in each module in order to handle the interface with the external files. The initiated data members of the struct are then passed to the function members of the module that are to be invoked in the upper-level applications. Several important modules of the telescope simulator are briefed below. The function of module `pix_detplan.c` is to layout chips on a **TDET** plane following the specifications (e.g., chip lower-left corner position and orientation, etc.) given in relevant parameter files. The motivation for introducing **TDET** is that the *AXAF* detector chips do not lie in a plane, making it difficult to inspect simultaneously both individual chip pixels and an overall geometry of the detector. To retain this information, chips are tiled in an approximately correct relative orientation, but the chip edges are paralleled and the gaps between the chips are edged. The `pix_grating.c` subsystem focuses on grating observation of a dispersed spectrum, determining the photon energy given a zero-order position for the undispersed photon trajectory, or traces the dispersed photon trajectory for a given energy. Module `pix_chip2stf.c` sets up **CHIP**, **CPC**, **LSI**, **STT**, and **STF** coordinate systems, and provides methods for the system transformations. Similarly, `pix_stf2tpc.c` and `pix_tpc2src.c` initiate the rest of coordinate systems and complete the transformations between **STF** and **CEL**.

By providing a rich collection of transformation functions, the "public" module hides the details of the implementations by wrapping one or more lower-level method(s). Unlike the lower-level programs, which are especially heavy on pointer manipulation, the upper-level functions are controlled by arguments passed by value. This type of manipulation was particularly desirable, since it allows FORTRAN-binding compatibility. Once the coordinate framework is built (or initiated), a requested transformation call from, say, **CPC** to **FP**, is able to output coordinates in **CPC** for given coordinates in **FP** without asking for other inputs.

3. Data Structure

The pixlib adopts SAO IRAF-compatible parameter file(s) as data I/O structure. There are six parameter files which are generalized from experimental or calibration data (McDowell 1996). These files specify several primary coordinate origins, relevant orientations, and others. Those are described as follows.

- `pix_origin_table.par` sets eleven *AXAF* primary coordinate system origins in spacecraft and HRMA nodal coordinates,
- `pix_tdet_planesys.par` defines nine **TDET** plane systems (dimension and center) of the five detectors,
- `pix_tdet_nomfocus.par` determines nominal focus points of **TDET** plane systems,
- `pix_tdet_refcoords.par` specifies the lower-left corner positions in **TDET** of 17 chips,
- `pix_corner_lsi.par` maps 2-D chip corner positions to 3-D **LSI** coordinates,
- `pix_sim_table.par` defines seven aim-points, the offsets from SIM transformation table (**STT**), of detectors, and
- `pix_size_cntr.par` constitutes 2-D instrumental pixel systems (i.e., **SKY**, **FP**, **TP**, and **GDP**) and grating properties.

The data are entered in the parameter files as a string, such as "(x, y, z)", in order to retain clarity. The string is interpreted back into the individual numbers when the file is opened. These coordinate system definition files are hidden from the user and looked up internally, once per run, in lower-level modules during the pixlib initiation. On the other hand, an additional parameter file is created specially for user interface. It allows the user to specify the chip of a detector, aim-point, focal plane system, etc. for performing a telescope simulation or data analysis.

4. Matrix Algorithm

The pixlib coordinate transformation computations are performed with matrix arithmetic. A portable matrix library package provides utilities to handle matrix algebra (i.e., vector-vector cross/dot/addition/subtraction, matrix(vector)-matrix multiple, matrix transpose/compose). Specifically, we use homogeneous coordinates (Salmon & Slater 1987) to simplify further matrix representation of coordinate transformations. Application of homogeneous coordinates to the ASC coordinate systems is briefly described below.

Coordinate transformation from frame A to frame B can be concisely expressed as $\wp(B) = F(A,B)\wp(A)$. Where $\wp$ is a 4×1 homogeneous coordinate vector, defined as $\wp \equiv (\ P_1 \quad P_2 \quad P_3 \quad 1\ )^T$ for a conventional 3-D spatial vector $(\ P_1 \quad P_2 \quad P_3\ )^T$. $F(A,B)$ is a 4×4 transformation matrix expressed in terms of rotation and translation matrices,

$$F(A,B) \;=\; \begin{pmatrix} R(A,B) & A_0(B) \\ O & I \end{pmatrix}_{4\times4}$$

$R(A,B)$ above denotes a 3×3 A-to-B rotation matrix, $A_0(B)$ a 3×1 translation (column) matrix of frame A origin in frame B. O is 1×3 zero matrix and I 1×1 unit matrix. To obtain the backward B-to-A transfer, $\wp(A) = F(B,A)\wp(B)$, the corresponding rotation and translation matrices for the $F(B,A)$ are derived, assuming $R(A,B)$ orthogonal, as

$$R(B,A) = R^T(A,B) \quad \text{and} \qquad B_0(A) = -R^T(A,B)A_0(B).$$

We use a transformation struct to compose the matrices, or arrays of $F[4][4]$, $R[3][3]$, and $A_0[3]$, for reusability. The struct is dynamically allocated and instantiated when a upper-level request is called. The values of A_0 and R elements are either taken from the parameter files or derived by parsing arguments, and the F are then composed with the known A_0 and R. The requested coordinate transformation from A to B is thus completed by a matrix-vector multiple performance.

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