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The AXAF Ground Aspect Determination System Pipeline

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Abstract. This article describes the *AXAF* aspect determination pipeline and its components, and highlights a procedure for determining centroids—a crucial step in deriving the post-facto aspect solution.

1. Introduction

The aspect determination system (ADS) is responsible for the collection of data that allow the pointing direction and roll angle of the *AXAF* Observatory to be reconstructed from the telemetry. The major parts of this subsystem are:

1. the aspect camera assembly (ACA) with its stray light shade,
2. the gyroscopes (inertial reference units—IRUs),
3. the fiducial light assembly, and
4. the fiducial transfer system.

The *AXAF* aspect camera is a 0.11 m diameter Ritchey-Chrétien telescope with a 3-element refractive corrector, which images about 2 square degrees of sky into one of two red-sensitive 1024×1024 CCDs. The optics of the camera are deliberately defocused, so that the FWHM of star image is about $9''$, well spread out relative to the CCD scale of $5''$/pixel. The aspect camera directly views the optical sky, and also views fiducial lights arranged around an X-ray detector, imaged via the fiducial transfer system consisting of a retroreflector/collimator and periscope (see Birkinshaw & Karovska 1995). Up to eight images (normally five guide stars and three fiducial lights) are tracked by the aspect camera, and their astrometry provides a history of the celestial pointing coordinates and roll angle for each X-ray observation.

2. Aspect Determination Pipeline

The Ground Aspect Determination System (GADS) pipeline is a collection of tools which process aspect telemetry and generate aspect data products. It

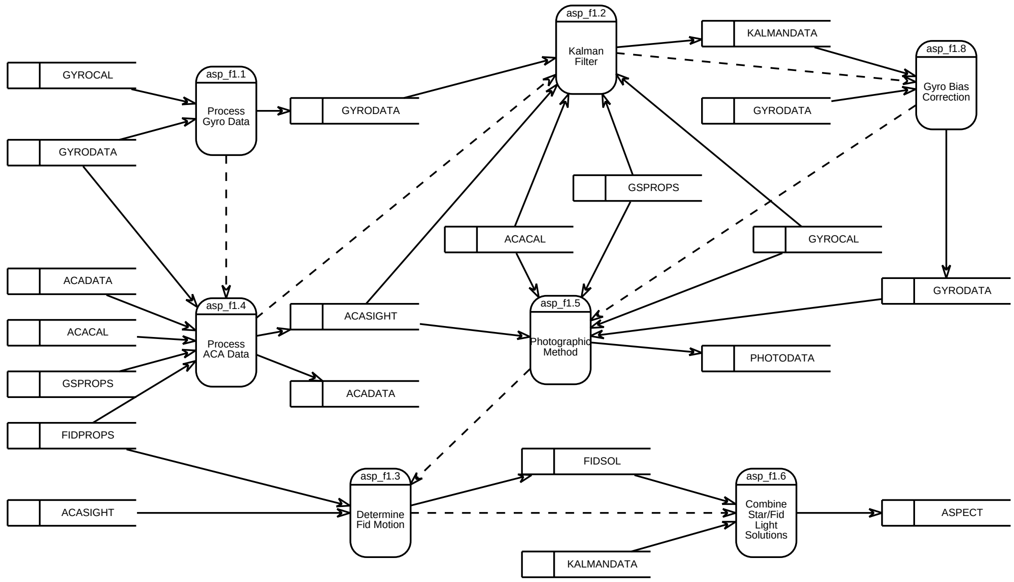

Figure 1. The Aspect Process Pipeline and its components.

produces a three-axis aspect solution in J2000.0 celestial coordinates, to support both image reconstruction (with error less than $0.5''$) and celestial location for X-ray data (with error less than $1''$).

The aspect solution is calculated from telemetry data (ACADATA and GYRODATA on Figure 1), generated by the aspect camera assembly and the inertial reference units (gyroscopes), using their associated calibration and alignment data (GYROCAL, ACACAL, GSPROPS, and FIDPROPS in Figure 1). The ACA telemetry contains pixelated images of stars between 10th and 6th magnitude and fiducial lights, nominally at 7th magnitude apparent brightness, at intervals of 1.025, 2.050, or 4.100 s (corresponding respectively to 4×4, 6×6, and 8×8 pixel images). The *AXAF* IRUs provide four axes of integrated angular rate telemetry at 0.25625 s intervals, from which three orthogonal axis rate data are derived.

The aspect camera data are analyzed to determine the centroid of each star or fiducial light image. The star centroids are combined with the IRU rate data in a Kalman filter to provide a time-varying optimal aspect solution and associated covariance matrix, assuming known noise models for the aspect camera and IRU data. The relative offsets between the star centroids and the fiducial light centroids are then calculated. Finally, the boresight calibration is applied to the relative offset, to transform the optical celestial aspect solution to the X-ray focal plane data. The GADS pipeline also performs a simple least-squares simultaneous fit of ACA position data and IRU rate data, and generates "photographs" of the ACA guide stars, for diagnostic and simple quality-assurance purposes. The pipeline also determines intervals during which the aspect solution is stable, assigns aspect quality indicators, and updates databases and the *AXAF* Optical Star Selection (AOSS) catalog.

The aspect pipeline consists of three components:

1. **Aspect Interval Separation Pipeline** makes one pass through IRU and ACA telemetry data to determine the aspect intervals during which major parameters (e.g., tracked star, spacecraft attitude) stay invariant or within allowed limits.

2. **Aspect Process Pipeline** processes ACA and gyro data, and derives aspect solution for each aspect interval.

3. **Assign Aspect Quality Pipeline** calculates aspect stable intervals, given the aspect solution, and assigns quality indicators to the aspect solution.

3. Aspect Process Pipeline

The Aspect Process Pipeline (Figure 1) is the central part of the aspect determination pipeline. The functional components of this pipeline are:

Process Gyro Data: Filter gyro data, check for internal consistency among the four gyro channels, and convert counts to angles. Gap-fill missing or filtered data, and calculate 3-axis spacecraft body angular rate.

Process ACA Data: Process aspect camera data, apply corrections, and calculate centroid coordinates (ACA sightings).

Kalman Filter: Optimally combine ACA star centroids and IRU data to determine ACA celestial location and image motion, using a Kalman filter and smoother. The Kalman filter and smoother also provides error estimates for the position and rate estimates in each axis, in the form of a covariance matrix.

Gyro Bias Correction: Correct bias drift rate using the estimate from the Kalman filter.

Photographic Method: Use photographic method for solving for the absolute celestial location and roll.

Determine Fiducial Motion: Perform a time-averaged solution of the fiducial light positions, calculate the fiducial light field centroid, and derive field motion as a function of time.

Combine Star/Fid Light Solutions: Calculate offset between fiducial light solutions and filtered star solutions, and apply boresight calibration, to generate image motion and celestial location at the focal plane science instrument.

4. Centroid Determination

We plan to use a PSF-fitting routine to calculate centroids and fluxes for each star and fiducial light image, where the PSFs obtained by interpolating from a database of theoretical PSFs of the optical system. Each model PSF is defined on a pixel grid that is finer than that of the aspect camera itself, and is calculated using the parameters of the optical system as measured before launch or on orbit.

Using a subset of ACA pixel data from the Aspect Interval, we identify poorly-fitting PSFs and find spoiler stars in star and fiducial light images. (Spoilers are faint stars in the vicinity of guide stars or fiducial lights). We then create new "effective" PSFs incorporating any spoilers, for image centroiding. We apply multidimensional χ^2 minimization routines (e.g., Powell minimization routine) to derive the optimal values for the coordinates and brightness of the image and the local sky background level.

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References

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