ADASS XV
ASP Conference Series, Vol. XXX, 2005
F. Ochsenbein, M. Allen and D. Egret eds.

Position Refinement of Spitzer-Space-Telescope Images

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Abstract. Position-refinement methods have been developed and are currently used in operations at the Spitzer Science Center to optimally register infrared astronomical images taken by the Infrared Array Camera (IRAC), one of the three science instruments onboard the Spitzer Space Telescope. The methods routinely involve frame-to-frame optimal matching of point sources in overlapping images and point-source matching to absolute-astrometric 2MASS-catalog sources. A recently-studied case consists of Spitzer observation campaign IRAC006800, in which 44,173 raw images were acquired in all four IRAC channels (corresponding to infrared spectral bands centered at 3.6, 4.5, 5.8, and 8.0 μm). An analysis demonstrated that, for images in the two shortest wavelength bands, the average radial separations between image sources and their absolute matched counterparts are reduced from $\approx$0.34 arcseconds to $\approx$0.17 arcseconds as a result of position-refinement processing. There are also improvements for images in the two longer wavelength bands, although not by as much (only a factor of $\approx$1.2 reduction) because the matched stars are fainter and the image data are noisier. An additional capability that will soon go online, called the super-boresight pipeline, is the simultaneous refinement of IRAC images from all four of its wavelength-band channels. This allows the pointing information gained from the shorter wavelength channels to benefit those at longer wavelengths.

1. Introduction

The quality of the science derived from astronomical images requires stable pointing and accurate absolute-pointing information. At the Spitzer Science Center (SSC), the pipeline processing of data-collection events (DCEs or raw images) from the Spitzer Space Telescope is done in several stages. The first stage processes individual raw images to remove instrument artifacts and convert the image-data units from data numbers (DNs) into absolute flux density. The second stage processes the telescope's 2-Hz, asynchronously-sampled boresight-pointing measurements over the image's exposure time to reject outliers, perform a three-dimensional rotation from the boresight to the center of the

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image, average the measurements to compute the mean R.A. (right ascension), Dec. (declination), and P.A. (pointing or twist angle about the boresight), and write these values as FITS-header keywords for each image. At the end of this stage, the resulting image product is called a "BCD" (basic calibrated data).

The subsequent ("post-BCD") processing stage involves several steps, including 1) BCD point-source extraction, 2) position refinement, 3) mosaicking, 3) mosaic/BCD point-source extraction, and 4) band-merging. The algorithm employed for position refinement of Spitzer Infrared Array Camera (IRAC) images in operations has been described by Masci *et al.* (2004). Characterizing the performance of the position-refinement step is central to this report because reducing errors in the position (R.A., Dec., P.A.) assigned to each image directly affects how well the images are co-registered for image mosaicking. The ability to maximize both the resolution and signal-to-noise ratio in mosaics, which result when the image positions are as accurate as can be, is pivotal to the work of astronomers.

In this paper, we present our statistical analysis of position-refinement performance from data taken in Spitzer campaign IRAC006800. Section 2 gives the salient features of the infrared array camera (IRAC). Section 3 briefly describes the data analyzed in this work. Section 4 presents the position-refinement performance. Section 5 discusses our new "super-boresight" software.

2. Infrared Array Camera (IRAC)

The IRAC instrument consists of four focal-plane-arrays with band-pass filters for imaging electromagnetic radiation in infrared spectral pass-bands centered at 3.6, 4.5, 5.8 and 8.0 μm (channels 1-4, respectively). The image acquisition is simultaneous in the four channels. Channels 1 & 3 share the same beam-split light and image the same piece of sky (to within a few pixels), as also do channels 2 & 4, except that their sky footprint is adjacent to, but does not overlap, the sky footprint for channels 1 & 3. Each raw image (DCE) has 256×256 pixels, and each pixel is square and $\approx$1.2 arcseconds on a side. The pixel detectors output signals that are 16-bit digitized and stored in onboard computer memory. Approximately every 12 hours, the image and telescope-pointing data are beamed to Earth and ultimately sent to the SSC for pipeline processing. More information about the IRAC instrument and Spitzer Space Telescope can be found at http://spitzer.caltech.edu.

3. Analyzed Measurements

The particular results presented in this paper are derived from Spitzer observation campaign IRAC006800. The campaign covered a 6-day period over roughly August 18-23, 2005. During that time, the Spitzer Space Telescope acquired 44,173 raw IRAC images in all four IRAC channels. Over 90% of the images in the campaign have exposure times ranging from 1 second to 100 seconds, with the remainder under 1 second. The campaign is segmented into 200 astronomical-observing requests (AORs) and 66 calibration requests, which were designed to study 48 different, widely-scattered astronomical objects/areas.

4. Pointing-Refinement Performance

The pointing-refinement methods used in Spitzer operations involve frame-to-frame optimal matching of point sources in overlapping images and point-source matching to absolute-astrometric 2MASS-catalog sources. The performance of these methods is assessed here. Each "sample" included in the statistical calculations below is associated with the position-refinement processing of an ensemble of BCD images from the same channel number that are ultimately mosaicked together (since each AOR consists of BCD images from multiple channels and ensembles, there are many more "samples" than AORs in the campaign). Position refinement for a given ensemble results in the computation of various statistical measures; of main interest here are the before and after average radial separations between image sources and their matches with absolute-astrometric 2MASS sources, denoted by δ_{before} and δ_{after}, respectively. Additionally, the average number of absolute sources matched per BCD during the position refinement of an ensemble of BCDs, N_{matches}, is noted. Table 1 gives the mean, standard deviation, and maximum value of these quantities for each channel over the entire campaign.

Table 1. Measured position-refinement performance for Spitzer campaign IRAC006800 using data parsed from archived *QAlogfile.txt* files (data units are arcseconds for δ_{before} and δ_{after}).

Channel	Statistic	Mean	Std. Dev.	Max. value
1	δ_{before}	0.336	0.108	0.813
	δ_{after}	0.155	0.0517	0.639
	N_{matches}	20.5	8.06	45.0
2	δ_{before}	0.347	0.113	0.833
	δ_{after}	0.182	0.0698	0.621
	N_{matches}	14.4	5.71	34.0
3	δ_{before}	0.673	0.384	2.42
	δ_{after}	0.550	0.389	2.33
	N_{matches}	2.48	2.59	29.5
4	δ_{before}	0.799	0.440	2.34
	δ_{after}	0.657	0.422	2.32
	N_{matches}	2.34	1.83	11.5

The number of samples for channels 1-4 are 1055, 1049, 663, 575, respectively. The fall-off in sample number is because the stars are dimmer at progressively longer infrared wavelengths, which leads to fewer or no absolute-source matches, especially for the shorter image-exposure times.

The main conclusions that can be drawn from these results are:

- Pointing refinement reduces the average radial separations between image sources and their absolute matched counterparts.

- The pointing-refinement improvement increases monotonically with decreasing channel number (wavelength).
- After position refinement, the standard deviations of the average radial separations between image sources and their absolute matched counterparts are smaller than before pointing refinement, except for channel 3 which has a slightly increased dispersion.
- The average number of matched absolute sources used in position refinement increases monotonically with decreasing channel number (wavelength). There is significant correlation between N_{matches} and position-refinement performance improvement (correlation coefficient=0.86 for a larger data set that includes four IRAC campaigns).
- The coefficient of variation after pointing refinement is smaller than before. The reduction is the least for channel 1 relative to the other channels, and the most for channel 3, the noisiest of the four IRAC channels.
- The differences between the "before" and "after" means are statistically very significant for all IRAC channels based on Student's t-test results.

These results are representative of overall Spitzer-mission performance, as evidenced by our comparisons with other IRAC campaigns.

5. New Super-Boresight Pipeline

A new process currently being tested at the SSC is called the "super-boresight pipeline". Position and uncertainty results from the refinement of individual IRAC channels are mapped back to the telescope system and combined to provide improved boresight pointing-history files, which can provide increased accuracy in subsequent re-processing, particularly for the longer-wavelength channels (3 and 4). Single-channel refinements for channels 3 and 4 typically have larger uncertainties and sometimes are not possible at all due to insufficient numbers of absolute-astrometric 2MASS-source matches.

Our early results indicate essentially no position bias between channels 1 and 2, but sub-arcsecond biases for channels 3 and 4. Adjusting the boresight data alone provides no means to remove channel-to-channel biases. To address this concern, the super-boresight software generates difference files, which may be used in the future to bring the channels into closer agreement by refining the Euler angles that separately relate each of the channels to the telescope system.

Acknowledgments. This work was performed at the Spitzer Science Center as part of a mission/project managed by Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration. The authors gratefully acknowledge the help of Ron Beck, Ed Jackson, Patrick Lowrance, Mark Lacy, and John Stauffer.

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