More Flexibility in Representing Geometric Distortion in Astronomical Images

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Abstract

A number of popular software tools in the public domain are used by astronomers, professional and amateur alike, but some of the tools that have similar purposes cannot be easily interchanged, owing to the lack of a common standard. For the case of image distortion, SCAMP and SExtractor, available from Astromatic.net, perform astrometric calibration and source-object extraction on image data, and image-data geometric distortion is computed in celestial coordinates with polynomial coefficients stored in the FITS header with the *PVi_j* keywords. Another widely-used astrometric-calibration service, Astrometry.net, solves for distortion in pixel coordinates using the SIP (Simple Imaging Polynomial) convention that was introduced by the Spitzer Science Center. Up until now, due to the complexity of these distortion representations, it was very difficult to use the output of one of these packages as input to the other. New Python software, along with faster-computing C-language translations, have been developed at the Infrared Processing and Analysis Center (IPAC) to convert FITS-image headers from *PV* to SIP and vice versa. It is now possible to straightforwardly use Astrometry.net for astrometric calibration and then SExtractor for source-object extraction. The new software also enables astrometric calibration by SCAMP followed by image visualization with tools that support SIP distortion, but not *PV*. The software has been incorporated into the image-processing pipelines of the Palomar Transient Factory (PTF), which generate FITS images with headers containing both distortion representations. The software permits the conversion of archived images, such as from the Spitzer Heritage Archive and NASA/IPAC Infrared Science Archive, from SIP to *PV* or vice versa. This new capability renders unnecessary any new representation, such as the proposed TPV distortion convention.

PV Distortion

- Implemented in SCAMP, Sextractor, Swarp & Aperture Photometry Tool
- Performed in intermediate world coordinate space (units are degrees)
- No special CTYPE*n* FITS keyword settings required
- Only forward transformation available (pixel to sky)

$$\begin{aligned} x' = {} & PV1\_0 + PV1\_1x + PV1\_2y + PV1\_3r + PV1\_4x^2 + PV1\_5xy + PV1\_6y^2 + PV1\_7x^3 + \\ & PV1\_8x^2y + PV1\_9xy^2 + PV1\_10y^3 + PV1\_11r^3 + PV1\_12x^4 + PV1\_13x^3y + PV1\_14x^2y^2 \\ & PV1\_15xy^3 + PV1\_16y^4 + PV1\_17x^5 + PV1\_18x^4y + PV1\_19x^3y^2 + PV1\_20x^2y^3 + PV1\_21xy^4 \\ & PV1\_22y^5 + PV1\_23r^5 + PV1\_24x^6 + PV1\_25x^5y + PV1\_26x^4y^2 + PV1\_27x^3y^3 + PV1\_28x^2y^4 \\ & PV1\_29xy^5 + PV1\_30y^6 + PV1\_31x^7 + PV1\_32x^6y + PV1\_33x^5y^2 + PV1\_34x^4y^3 + PV1\_35x^3y^4 \\ & PV1\_36x^2y^5 + PV1\_37xy^6 + PV1\_38y^7 + PV1\_39r^7 \end{aligned} \quad (1)$$

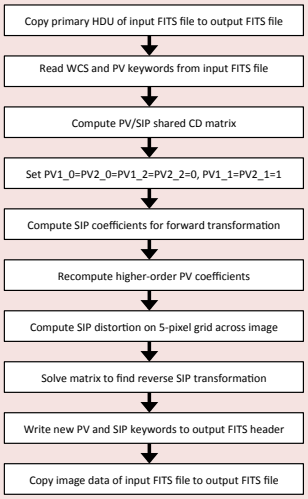
$$\begin{aligned} y' = {} & PV2\_0 + PV2\_1y + PV2\_2x + PV2\_3r + PV2\_4y^2 + PV2\_5xy + PV2\_6x^2 + PV2\_7y^3 + \\ & PV2\_8xy^2 + PV2\_9x^2y + PV2\_10x^3 + PV2\_11r^3 + PV2\_12y^4 + PV2\_13xy^3 + PV2\_14x^2y^2 \\ & PV2\_15x^3y + PV2\_16x^4 + PV2\_17y^5 + PV2\_18xy^4 + PV2\_19x^2y^3 + PV2\_20x^3y^2 + PV2\_21x^4y \\ & PV2\_22x^5 + PV2\_23r^5 + PV2\_24y^6 + PV2\_25xy^5 + PV2\_26x^2y^4 + PV2\_27x^3y^3 + PV2\_28x^4y^2 \\ & PV2\_29x^5y + PV2\_30x^6 + PV2\_31y^7 + PV2\_32xy^6 + PV2\_33x^2y^5 + PV2\_34x^3y^4 + PV2\_35x^4y^3 \\ & PV2\_36x^5y^2 + PV2\_37x^6y + PV2\_38x^7 + PV2\_39r^7 \end{aligned} \quad (2)$$

SIP Distortion

- Implemented in MOPEX, DS9, WCSTools, Aperture Photometry Tool, etc.
- Performed in image coordinate space (units are pixels)
- Suffix "-SIP" required in CTYPE*n* FITS keyword settings
- Useful when the distortion is constant from image to image
- Forward and reverse transformations included (iterative solution not req.)

$$\begin{pmatrix} x' \\ y' \end{pmatrix} = \begin{pmatrix} CD1\_1 & CD1\_2 \\ CD2\_1 & CD2\_2 \end{pmatrix} \begin{pmatrix} u + \sum_{i,j} A_{i,j} u^i v^j \\ v + \sum_{i,j} B_{i,j} u^i v^j \end{pmatrix} \quad (3)$$

PV-to-SIP Conversion Algorithm Flow Chart



The Palomar Transient Factory

- Multi-epochal robotic survey
- Palomar 48" telescope
- 100 MP camera, 11 CCD images
- Fully operational since March 2009
- Transient phenomena studies
- New supernovae discoveries
- Images processed at IPAC
- Data archived at NASA/IPAC IRSA

Objectives, Requirements & Assumptions

- PTF images have moderate geometrical distortion (4th-order polynomials)
- Variable observing weather and seeing requires that each PTF exposure have a separate distortion characterization
- It is critical to preserve the individual images without remapping onto a sky grid, to best preserve the ability to detect and measure transient events
- Users of PTF images, therefore, need access to a wider range of tools than has previously been the case.
- If the radial terms are not used (SCAMP omits them), exact conversion is possible (cf. Eqs. 1-3)
- For good form, distortion should be forced into quadratic and higher polynomial terms
- The CD matrix can be recomputed for sharing between SIP and *PV* distortion
- PTF image FITS headers can include both SIP and *PV* distortion representations, for processing by SExtractor and viewing in DS9 with accurate astrometry (append "-SIP" suffix to CTYPE*n* FITS keywords)
- Distortion-conversion software programs are needed for the PTF project

New Software for *PV*-to-SIP and SIP-to-*PV* Conversion

- *Sage* was used to solve the equations using symbolic calculations
- Conversion software programs *pv2sip* and *sip2pv* were developed
- Coded in the C language for fast computing speed (prototyped in Python)
- The software is currently limited to 4th polynomial order
- Benchmarked at 3.7 s (*pv2sip*) and 0.5 s (*sip2pv*) for conversion of a single PTF image on a MacBook Pro laptop with a 2.2 GHz Intel Core i7 processor and 4 GB of memory and running Lion OS X
- More than 2 million PTF images have been processed with *pv2sip*, with a failure rate of only 0.0116%
- Our proven methods render the proposed new TPV convention unnecessary

For more information:

Full SPIE paper, including our full assessment of the proposed new TPV convention (http://spider.ipac.caltech.edu/staff/laher/ptf/spie.pdf)

Russ' Aperture Photometry Tool, an interactive GUI with useful tools and both SIP and *PV* support (download from www.aperturephotometry.org)

The Palomar Transient Factory (http://www.astro.caltech.edu/ptf)