Astronomical Data Analysis Software and Systems VII
ASP Conference Series, Vol. 145, 1998
R. Albrecht, R. N. Hook and H. A. Bushouse, eds.

The Astrometric Properties of the NOAO Mosaic Imager

L. E. Davis

National Optical Astronomy Observatories, Tucson, AZ 85719

Abstract. The astrometric properties of the NOAO Mosaic Imager are investigated using the new IRAF MSCRED and IMMATCHX packages and observations taken during recent engineering runs.

1. Introduction

The NOAO Mosaic Imager is an 8K by 8K pixel camera composed of 8 individually mounted 2K by 4K CCDs separated by gaps of up to 72 pixels. Each CCD has its own amplifier and is read into a separate image in a multi-extension FITS file. A set of dithered exposures is required to obtain a complete observation of a given region of the sky. Reassembling an observation into a single image requires selecting the reference coordinate system of the final combined image, resampling each exposure to the selected reference coordinate system, and combining the resampled images.

In this paper the new IRAF MSCRED and IMMATCHX packages and data obtained during recent Mosaic Imager engineering runs on the NOAO 4m (FOV 36 arcminutes, scale 0.26 arcseconds per pixel) and 0.9m (FOV 59 arcminutes, scale 0.43 arcseconds per pixel) telescopes are used to investigate the functional form of the plate solutions, the accuracy of the plate solutions before and after resampling and combining, and the accuracy of the flux conservation in the resampling and combining steps. At the end of the paper some speculations are offered on the feasibility or otherwise of reassembling the Mosaic Imager data in real time at the telescope.

2. The Plate Solutions

The plate solutions were computed using published astrometry for Trumpler 37 (Marschall and van Altena 1987) and data from recent engineering runs. Fits to both gnomonic projection (TAN) plus polynomial in x and y models (Kovalevsky 1995), and zenithal polynomial projection (ZPN) models (Greisen and Calabretta 1996) were performed.

2.1. 4m Plate Solutions

A theoretical 5th order ZPN model for the 4m prime focus plus corrector optical system was available at the time of writing (Vaughnn 1996). This model predicted pincushion distortion with a maximum scale change of 6.4% and maximum pixel area change of 8.5% across the FOV. Fits of ~400 stars in Trumpler

37 to the theoretical model produced good plate solutions for each CCD with residuals for the 8 detectors averaging ˜0.10 and ˜0.07 arcseconds in α and δ respectively. Marginally better residuals of ˜0.09 and ˜0.06 arcseconds were obtained with TAN projection plus cubic polynomial models. The residuals from the latter fits showed no evidence for the predicted 5th order term, most probably due to a combination of the limited angular size of the individual CCDs, and the precision of the published astrometry.

2.2. 0.9m Plate Solutions

An accurate theoretical model for the 0.9m f/7.5 Cassegrain focus plus corrector system was not available at the time of writing. However TAN projection plus cubic polynomial model fits to ˜800 stars in the field produced good plate solutions, with residuals for the 8 CCDs averaging ˜0.07 arcseconds in both α and δ and no systematic trends in the residuals. The polynomial fits revealed the presence of a 1.8% maximum scale change and 2.0% maximum pixel area change over the FOV. These results were used to derive the equivalent "theoretical" ZPN model. Fits of the derived ZPN model to the data produced good plate solutions with residuals of ˜0.09 arcseconds in each coordinate.

3. Reassembling a Single Mosaic Observation

The TAN projection plus cubic polynomial plate solutions and bilinear interpolation were used to combine the 8 pieces of the mosaic into a single 8K by 8K image with an undistorted TAN projection coordinate system. Because the individual images were flat fielded before resampling, no additional flux correction during resampling was required. Empirical rather than theoretical plate distortion models were used in order to test the validity of the empirical approach, and because they produced marginally better fits. Bilinear interpolation was chosen for efficiency, The TAN output coordinate system was chosen because it is the standard projection for small field optical astrometry. Other options are available.

3.1. Astrometric Accuracy

New plate solutions were computed for the resampled 4m and 0.9m data. In both cases TAN projection plus first order polynomials in x and y produced good plate solutions with residuals of ˜0.08 / ˜0.06 and ˜0.10 / ˜0.09 arcseconds in the α / δ coordinates fits for the 4m and 0.9m images respectively. In all case no discernible distortion remained, and the accuracy of the original plate solutions was almost recovered.

3.2. Flux Conservation

Before and after resampling aperture photometry of the astrometric stars was obtained and compared with flux correction model derived from the ZPN radial distortion models. Agreement for the 4m data was excellent with <correction (observed) - correction (predicted)> = 0.0007 +/- 0.01 magnitudes, and no observed trends with distance from the center of the image. The corresponding numbers for the 0.9m data were, <correction(observed) - correction(predicted)>

= 0.0004 +/- 0.018 magnitudes, and no trends with distance from the center of the image. Therefore as long as the coordinate transformation used to resample the image models the geometry of the optical system accurately, the resampling code used to recombine the images will accurately conserve flux.

4. Combining Dithered Mosaic Observations

The dithered resampled observations must be combined to fill in the gaps in the mosaic and produce a single image with complete sky coverage. Combining the dithered observations requires precomputing the offsets between the frames in a dither set (before resampling), and resampling the dithered images to the selected reference coordinate system (TAN with no distortion) in such a manner that the images are separated by integer pixel offsets, and combining the intensities in the overlap regions. At the time of writing only a single 0.9m set of dithered Trumpler 37 observations was available for investigation.

4.1. Astrometric Accuracy

A new plate solution was computed for the combined images. A TAN projection plus first order polynomials in x and y model produced an excellent fit with residuals of ˜0.09 arcseconds in α and δ. Therefore the combining step did not introduce any distortion into the image geometry and the accuracy of the original plate solutions was approximately recovered.

4.2. Flux Conservation

The image combining algorithm employed was median with no rejection. Before and after aperture photometry of ˜800 astrometric stars around the combined frame and one of the resampled frames produced a mean value of <mag (resampled) - mag (combined)> = -.008, and no trends with position in the image. The small but real offset appears was caused by changing observing conditions which was not corrected for in the combining step.

5. Automatic Image Combining at the Telescope

5.1. Plate Solutions

Automating the image combining step to run in close to real time requires that either the plate solutions are repeatable from night to night and run to run, or a mechanism is in place to automatically compute new plate solutions at the telescope. Thus far only the first option has been investigated, although the second is also being considered. Preliminary tests suggest that the higher order terms in the plate solutions are very repeatable, but that small adjustments to the linear terms are still required. More rigorous testing with the system in a stable condition is required to confirm this.

5.2. Efficiency

On an UltraSparc running SunOS 5.5.1, a set of nine dithered images currently takes approximately ˜2 minutes per image to read out, ˜4 minutes per image to reduce, and ~10 minutes per image to resample. A further ~18 minutes is required to combine the 9 resampled dithered images. Cpu times are ~1/2 to ~1/3 of the above estimates, depending on the operation. Although a factor of 2 improvement in efficiency may be possible through system and software tuning in some cases, it is obvious from the time estimates above that only some observing programs can realistically consider combining images at the telescope in real time and under current conditions.

5.3. Software

Much of the image combining process has already been automated, however some more automation in the area of adjusting the plate solutions for zero point and scale changes needs to be done.

6. Conclusions and Future Plans

The individual mosaic pieces can be recombined with high astrometric accuracy using either the empirical TAN projection plus cubic polynomial models or the theoretical ZPN models. The latter models have fewer parameters than the former and are a more physically meaningful representation of the data, but the former still produce lower formal errors.

As long as the computed plate solutions are a good match to the true geometry of the instrument flux conservation during resampling is very accurate. If this is not the case another approach must be taken, such as using a precomputed "flat field" correction image.

Automating image combining at the telescope is currently only feasible for some types of observing programs. The main limitation is the computer time required. The repeatability of the plate solutions from run to run and the issue of computing plate solutions at the telescope are still under investigation.

Acknowledgments. The author is grateful to Frank Valdes for assistance with the use of the MSCRED package and to Taft Armandroff and Jim Rhoades for providing test data.

References

Greisen, E. R. & Calabretta, M. 1996, Representations of Celestial Coordinates in FITS, fits.cv.nrao.edu fits/documents/wcs/ wcs.all.ps

Kovalevsky, J. 1995, in Modern Astrometry, Springer-Verlag, 99

Marschall, L. A. & van Altena, W. F. 1987, AJ, 94, 71

Vaughnn, D., 1996, private communication