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Basis for a SOAR optical imager pipeline

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Abstract. The development of CCD mosaics had been incorporated into the majority of the recent observing facilities, including on SOAR. We discuss the treatment of mosaic CCD exposures including basic instrumental calibration, the creation of bad pixel masks, the removal of cosmic rays and fringes by sky flat-fielding, the set up of a World Coordinate System by astrometric calibration and the removal of the gap by the creation of single, deep images out of a set of dithered exposures. We have assembled these image treatment programs on a series of semi-automated IRAF scripts¹ to handle the reduction of general SOAR Optical Imager (SOI) images requiring little on none user interaction.

Resumen. El desarrollo de mosaicos CCD ha sido incorporado recientemente en la mayoría de los observatorios modernos, entre ellos SOAR. En este trabajo describimos el tratamiento de imágenes mosaico SOAR en sus diferentes etapas: calibraciones instrumentales básicas, generación de una máscara para eliminación de pixeles malos, remoción de rayos cósmicos y *fringes*, ajuste del WCS a través de calibraciones astrométricas y remoción de *gaps* en la imagen simple profunda generada a partir de varias imágenes mosaico. Hemos redactado diferentes rutinas de procesamiento de dichas imágenes para que puedan ser ejecutadas de un modo semi-automático dentro de un entorno IRAF.

1. Preparing the Headers

Some important keyword headers corrections include:

- OBJECT: dithered exposures of the same object should have the suffixes _10E and 20E, if displaced by 10'' and 20'' to east, for example, for ease of identification. This will be required when resampling and combining the images into a single exposure.
- GAIN, RDNOISE: for an adequate instrumental calibration, it is desirable to process each amplifier with its own instrumental signature. Individual gain and read-out noise values are re-calculated for each amplifier using raw calibration images.

¹They can be requested from the first author.

- CRPIX1, CRPIX2: in order to perform the astrometric calibration a crude world coordinate system must be set up. A first approximation ties the telescope pointing coordinate with the center of the mosaic camera in each amplifier.
- CCDNAME, CCDSEC: tasks from the package `mscred` identifies the relative positions of amplifiers in the camera by these keywords. Amplifiers on the same CCD were correctly identified providing proper mosaic display and correct merging at the instrumental calibration.

2. Instrumental Calibration

We discuss on their differences with respect to single CCD images:

- basic instrumental calibration (**bias/overscan subtraction, dome flat-fielding, trimming of overscan regions**) are performed on each amplifier image individually (E2V CCD 4096×2048 , FOV $5.25' \times 2.62'$, scale= $0.077''/\text{pix}$);
- any scale or normalization operation are done uniformly over all amplifier images;
- amplifiers images read from the same CCD chip are merged after the removal of their overscan strip, leaving MEF mosaics with one extension per CCD chip;
- a static bad pixel mask is created from the calibration MEF mosaics and updated into individual bad pixel masks by the addition of the identified cosmic rays and saturated pixels.

The calibrated images presented a more uniform background brightness as the relative gains between its amplifiers have been compensated (see Fig. 1).

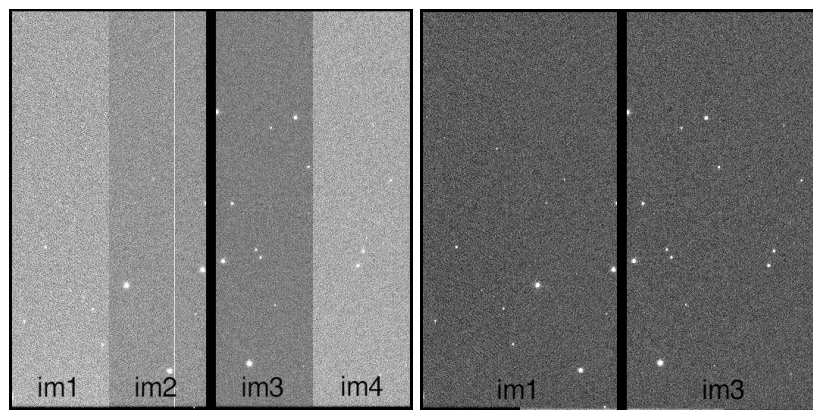


Figure 1. Raw image with header corrections (left) and after removal of instrumental bias (right).

3. Sky flat-fielding

Sky flat-fielding processing steps consist of :

- selecting the longest exposure of each object to create the sky-flat; dithered exposures of the same frame were considered distinct objects for this purpose.
- combining the selected exposures into a preliminary sky-flat, which was further processed by a median filtering operation to reject pixel-to-pixel sensitivity variations and to generate a smoother sky flat-field;
- removing the mean background level from the sky flat-field by surface fitting or median/average block filtering using large box sizes to generate a fringe pattern, which was subsequently removed from each frame after being scaled to the frame exposure time;
- dividing the resulting sky flat-field into each science image.

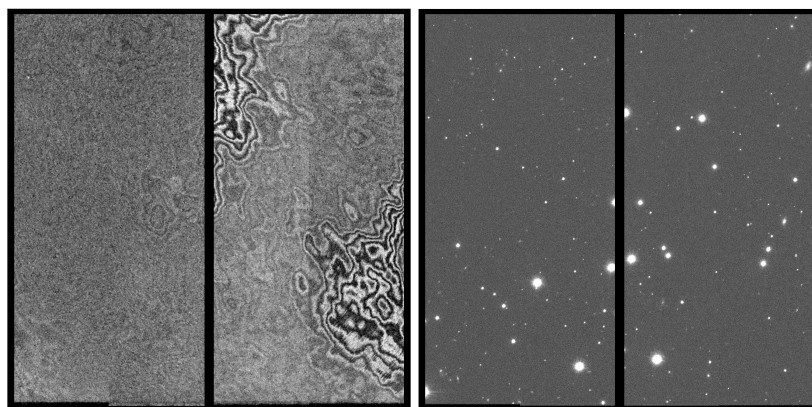


Figure 2. Sky flat-field before fringe correction (left) and a 20 seconds exposure (right) after fringe removal and sky flat-field correction.

4. Astrometric calibration

The astrometric calibration is performed with the following steps:

- an initial WCS is derived interactively, for each mosaic extension, by matching the brightest objects on a supplied reference image with the corresponding sources on an astrometric catalog. A WCS function is then computed by using all matched catalog sources in the field of view;
- the derived plate solution is used to generate an initial WCS on other exposures. This initial WCS is then refined by an automatic rematching of catalog sources and exposure objects, to account for small deviations caused by telescope pointing errors, atmospheric changes and filter differences.

- for each image group pertaining to the same object: short exposures derived their initial WCS solution from longer exposures on the same filter, these derived their solution from the longest exposure on the same filter as the reference image; the latter derived their WCS solution from the reference image.

The RMS residuals of the celestial positions of the stars were ≈ 0.2 arcseconds on the reference object images and ≈ 0.4 arcseconds on other objects images, where the WCS solution was "carried" into.

5. Resampling and combining

Images are resampled and combined according to the following procedures:

- all mosaic images are resampled into geometrically corrected single images;
- exposures pertaining to the same dither set have their WCS origin tied to the same reference point, so that their relative positions can be readily determined when stacking them into a single image.
- exposures pertaining to the same dither set are photometrically matched to account for varying sky brightness and atmospheric transparency between the exposures in the set;
- exposures pertaining to the same dither set are stacked (combined) to create single, deeper images without the CCDs gap.

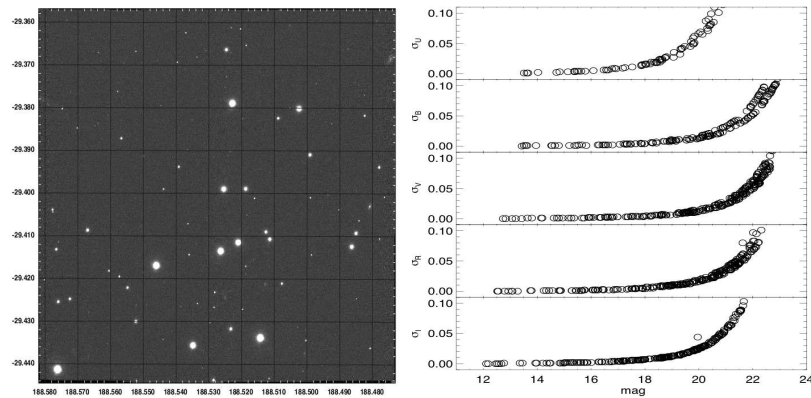


Figure 3. Resulting stacked image of 3 dithered 20 sec exposures (left) and photometric errors derived from PSF photometry of the images (right).

References

- Tody, D., Valdes, F. 1998, *Guide to NOAO Mosaic Data Handling Software*,
 Valdes, F., 2001, *The reduction of CCD Mosaic Data*, in *Automated Data Analysis in Astronomy*, ed. H. P. Singh and R. A. Gupta