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Live, on-site data processing and photometry for SOAR imagers

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Abstract. We present a set of data processing modules designed to perform live, on site data reduction, quality assessment and aperture photometry of images acquired on the SOAR telescope. The modules are designed for the optical imagers (i.e. SOI, SAMI and Goodman Imager) in the context of the VISCACHA project, but can be easily adapted to other imaging cameras and even to instruments on other telescopes (e.g. OPD). They are being developed in Python, using the Astropy and NumPy packages, obtaining unparalleled performance through multiprocessing capabilities that can be scaled to use the full power of multi-core computers and clusters. Their short processing times makes it possible for the modules to run live, on site, processing the images as they are acquired by the telescope.

Resumo. Apresentamos um conjunto de módulos de processamento de dados desenvolvidos para realizar redução, controle de qualidade e fotometria de abertura nas imagens obtidas com o telescópio SOAR, ao vivo, i.e. à medida que são obtidas no sítio. Os módulos estão sendo desenvolvidos para as câmeras imageadoras (i.e. SOI, SAMI e Goodman) no contexto do projeto VISCACHA, mas podem ser facilmente adptadas para outros instrumentos e até mesmo para outros telescópios (e.g. OPD). Eles estão sendo construídos em Python, usando as bibliotecas Astropy e NumPy, obtendo performance excepcional através de multiprocessamento que pode ser escalonado para extrair o máximo de perfomance de computadores multi-núcleos e clusters. Esta performance permite que os modulos operem ao vivo no telescópio, processando as imagens conforme elas são adquiridas.

Keywords. Techniques: image processing – Techniques: photometric – Astrometry

1. Introduction

The emergence of the next generation of telescopes heralds a new era in astronomical observation, with facilities like the European Extremely Large Telescope (Neichel et al. 2018), the Thirty Meter Telescope (Sanders 2013), and the Vera Rubin Observatory (Ivezić et al. 2019) poised to revolutionize our understanding of the cosmos. These state-of-the-art observatories are going to generate unprecedented volumes of data on a nightly basis, presenting serious challenges in terms of storage, management, reduction, and post-processing. Additionally, the increasingly complexity of the acquired data is often an obstacle for the astronomical community, posing a potential bottleneck in the scientific exploration of the data. In that sense, the integration of automated pipelines has evolved from a mere convenience to an indispensable component within these next-generation observing facilities, and in modern astronomy in general. These automated systems play a pivotal role in streamlining and expediting the intricate processes of data processing and reduction, ensuring that researchers can focus in their scientific investigation, using properly processed and reliable data.

We are presenting a set of tools designed to provide similar enhanced products for the SOAR imagers. They perform basic data reduction, cosmic ray removal, astrometric calibration and source detection and segmentation, delivering a catalog of the detected celestial objects along with their photometric and morphological properties. They are completely written in Python, using mainly the Astropy (Astropy Collaboration et al. 2022) and NumPy (Harris et al. 2020) packages, and optimized for efficiency through multiprocessing to operate live on the telescope delivering its products in real time. With IRAF being slowly phased out of use and the increasing costs of proprietary programming languages, a free, open and reliable reduction platform is on demand for the SOAR telescope.

2. Data reduction

Basic data reduction is performed using the methods and classes in Astroyy affiliated package ccdproc (Craig et al. 2017), to perform the usual reduction routine. Since most of the imaging cameras features multiple detectors and/or amplifiers, the reduction is carried out independently (and concurrently) on each amplifier. Overscan correction is modelled at each row of the overscan strip by using a simple median and then subtracted from the image. Overscan corrected bias frames are average combined into a master bias frame, using a sigma clipping algorithm (at 3-sigma level) to remove outliers. Bias correction is performed by subtracting the master bias frame from the target images. Overscan and bias corrected flat-field frames are normalized and then median combined into a master flat-field image for each filter, using a sigma-clipping algorithm (at 3-sigma level). Since most flat-field taken at SOAR are actually twilight sky frames, their normalization to a common level must be done prior to the sigma-clipping operation. Even though ccdproc Combiner class does have these functionalities, they do not appear to be working properly (ver. 2.4) when used together. This was solved by turning off Combiner normalization and devising a function to estimate each flat-field image normalization factor from the histogram mode of the counts (as done by IRAF) in a customizable central region of its first amplifier. Flat-field correction is done by dividing the images by the corresponding master flat-field of the same filter. Finally, science images are reduced by performing overscan, bias and flat-field corrections over each image amplifier. Fig. 1 compares the outcomes of the basic reduction process for images from 3 different SOAR imagers.

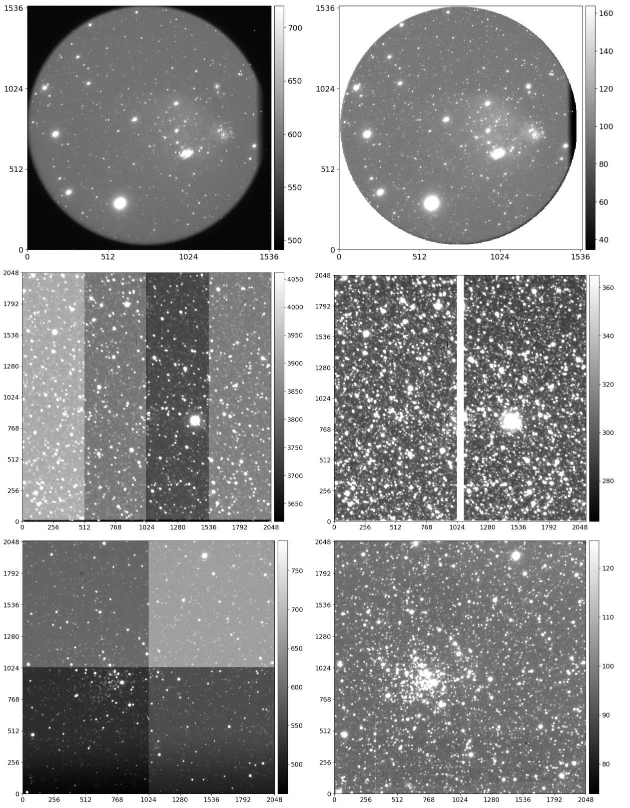

Figure 1. Raw (left) and reduced (right) sample images taken with SOAR imagers Goodman (top), SOI (centre) and SAMI (bottom).

3. Astrometry

The astrometric solution is determined by identifying sources in the image with instrumental coordinates (x, y) and matching them to an astrometric catalog with celestial coordinates (α, δ), in order to solve the following equation:

$$\begin{pmatrix}\alpha-\mathtt{CRVAL1}\\ \delta-\mathtt{CRVAL2}\end{pmatrix} = \begin{pmatrix}\mathtt{CD1\_1} & \mathtt{CD1\_2}\\ \mathtt{CD2\_1} & \mathtt{CD2\_2}\end{pmatrix}\begin{pmatrix}x-\mathtt{CRPIX1}\\ y-\mathtt{CRPIX2}\end{pmatrix} \tag{1}$$

where the keywords `CRVAL`i, `CRPIX`j, and `CD`i`_`j are the main header units composing the image World Coordinate System (WCS) (Calabretta & Greisen 2002).

It can be shown that Eq. 1 is equivalent to applying a translation (T), rotation (R) and scale change (s) operations to an initial set of coordinates as shown below:

$$\begin{pmatrix}\Delta\alpha\\ \Delta\delta\end{pmatrix} = s.\mathbb{I}\times\vec{R}\cdot\left[\begin{pmatrix}\Delta x\\ \Delta y\end{pmatrix}+\vec{T}\right] \tag{2}$$

where the translation offset would be applied directly to the `CRPIX`j keywords and the rotation angle and scale factor would determine the `CD`i`_`j keywords. In this notation, we can take advantage of the Kabsch-Umeyama algorithm (Kabsch 1976; Umeyama 1991), which determines, algebraically, the optimal similarity transformation parameters (rotation, translation, and scaling) that matches two point patterns in a multi-dimensional space.

We have found, however, that the Kabsch-Umeyama algorithm can be unreliable if the translation offset is too large. To solve that issue, we have implemented a brute force coarse search function which finds the coordinates offset maximizing the number of catalog matches within 3 arcsec of each instrumental source (Fig.2). Afterwards, the Kabsch-Umeyama algorithm was used to fine tune the translation and derive the optimal rotation change. If the instrument plate scale is properly recorded in the header WCS (e.g. on the `CDELT`j keywords), the scale parameter can be kept fixed at 1, as the algorithm will always converge to that value.

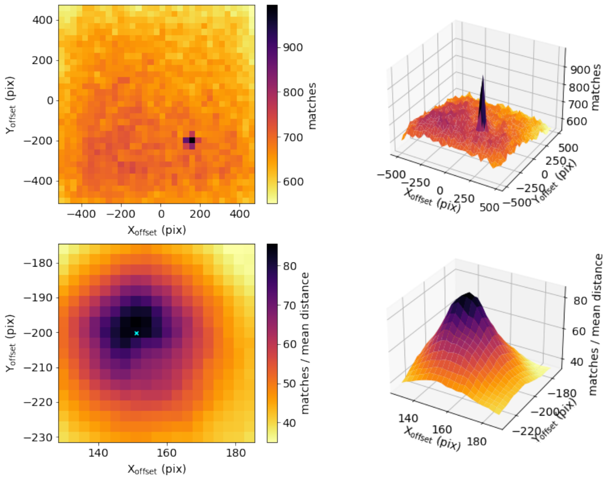

Figure 2. Translation coarse search done within 500 pixels of the initial guess provided by (`CRPIX1`,`CRPIX2`) value (Top pannel). The offset found was $(\Delta x, \Delta y) = (150, 200)$, as it can be seen on the zoom around the peak value (bottom pannel).

4. Performance

Currently, on a modern 10 core computer, the basic reduction of a science image takes negligible time (i.e. less than 1 second) while the astrometric solution is dominated by the catalog query time (a few seconds). These short processing times makes it possible for the modules to run live, on site, processing the images as they are acquired by the telescope.

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