DOI: http://dx.doi.org/10.18524/1810-4215.2017.30.114458

ASTRONOMICAL IMAGE PROCESSING FOR HIGH-ACCURATE ASTROMETRY DATA

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ABSTRACT. This article presents the main results of the initial processing of some of the astronomical images obtained from the archive of the digitized photographics survey of the whole sky SuperCOSMOS. Using of the median filtering and gausian convolution procedure with the adaptive kernel allows to carry out the initial processing of astronomical images without calibration frames. After the initial processing, the photocenters of the celestial objects were identified by various methods. It has been concluded that after the use of the mathematical methods for the initial processing of the digitized photographics images, the position of objects is calculated with a higher random and systematic precision.

Keywords: astrometry; survey; image processing; big-data

1. Introduction

Huge strides in the development of telescope construction and radiation detectors have led to the exponential growth of the amount and quality of data in modern and future sky surveys. These factors have opened up new research horizons for astronomers, but they require new approaches to the processing of astronomical images. This article focuses on one of the most important computational problems of astronomy: the processing of raw astronomical data. Today, the resolution of the astronomical images resulting from the digitizing of photographic plates is up to several Gpixel. To processing such astronomical images, the use of large computational power and optimal algorithmic solutions is needed. At the present time, computer technology gives the ability to create and fully manage the files that contain several gigabytes of data.

For quality reduction, there are many different factors to consider from the observation and the specifics of the instruments up to atmospheric effects that are very difficult to describe. However, now there is a large number of different software packages, tools, and instruments in the automatic or semi-automatic mode designed for the high-quality initial processing of astronomical images. In modern observations with the using of CCD, high-quality results are achieved by means of calibration frames such as Offset, Dark, Flat. When such frames are absence, different mathematical methods have to be applied.

Today, computer technology makes it possible to effectively analyze the astronomical archives that contain even terabytes of astronomical images (Vavilova et al., 2012). For the processing of astronomical images, such software packs as IRAF, IDL, MIDAS, etc. have been developed and widely used. But since most of them have some particularities in use, in other words, they are targeted at specific purposes, apply-ing them to our purposes will not produce the desired results. Also, our research has shown that the software packs listed above cannot work with very large images or show very low performance. Therefore, it has been decided to develop our own software package that will effectively handle large amounts of astronomical image.

2. Photographic survey of the whole sky

In April 2018, there will be available the Gaia DR2 catalogue of over 1 billion stars position and proper motion (Gaia Collaboration, 2016). Precision in proper motions will be higher than 1 mas/year for the stars from 4 to 20.7 G mag. This catalogue will be based on the observations of the 5-year GAIA space mission. Short-term ground based astrometric surveys use Gaia DR1 as reference frame. Studying any complex motion or variable centroid objects, i.e. "time domain astronomy" requires observations at multiple, specific epochs or long time-line observations. To solve this problem, all digitized photographic whole sky surveys that were received from the 1950s up to 2000, as well as all available modern CCD surveys, have to be processed. This requires the creation of the software that will effectively processing digital photographic surveys at the modern astrometric precision levels.

In 2020, it is planned to launch an 8-meter LSST telescope that will be scaning the available sky over a few days. During only one night of observation with the use of the largest CCD matrix (3 Gpixel), about 15 TB of data will be received (Juric et al., 2015). The size of each image will be up to several GByts. Therefore the problems of software development, new processing algorithms, and new methods for analyzing the large amounts of data are especially acute.

In order to support the above listed tasks, a new software has been developed. The analysis of the efficiency and correctness of the software operation was performed on images obtained from the digitizing of the northern photographic surveys of POSS and southern SERC, ESO, which are stored in Edinburgh SuperCOSMOS Scientific Archive (SSA) (Hambly et al., 2001, Hambly et al., 1998). One such FITS-image is an area of the celestial sphere of 6x6 degrees size, with a resolution of 0.67 arcseconds per pixel. The size of a FITS image is about 1Gpixel (32256x32256px), which is about 2 GByts of data in the digitized form.

3. Processing

3.1. Initial processing

The main peculiar properties of work with the photographic surveys is that they do not contain supporting calibration frames (Offset, Dark, Flat), so for the initial processing only the use of mathematical methods was needed.

To align the image field and to eliminate the noise, the median filtering with the variable (dynamic) kernel, as well as the mathematical convolution method with the Gaussian kernel were applied. Unfortunately, at this stage of the work some of the objects are not taken into account because of their irregular shape. For now, we are improving approaches to these methods in order to obtain undistorted data on the maximum number of objects.

The size of the median filter kernel ranged dynamically from the initial 3x3 pixels to the 50x50 pixels, and it includes the information of the part of the image which it overlaps while operating (Popowicz et al., 2015). The limitation of the maximum kernel size made it possible to exclude very bright objects (magnitude < 8) that could have obscured the surrounding weaker objects.

The convolution operation in our work helped to clarify the edges of the celestial objects, as well as "smooth" their brightness distribution on the field, which ultimately gives each of them a more "correct", Gaussian form.

3.2. Calculation photocenter of the objects

The position of the objects in the SuperCOSMOS was obtained by the fastest but at the same time the least accurate method known today (Center of Gravity, which is also referred to as the Moment method)

$$(x_b, y_b) = \left(\frac{\sum_{ij} W_{ij} I_{ij} x_{ij}}{\sum_{ij} W_{ij} I_{ij}}, \frac{\sum_{ij} W_{ij} I_{ij} y_{ij}}{\sum_{ij} W_{ij} I_{ij}} \right).$$

It's worth remarking that the improved kinds of this method exist, such as Weighted center of Gravity and Iterative center of Gravity. Their precision in finding centroids is several times higher.

Fig. 1 shows theoretical dependence the precision calculation of the photocenter from objects size in pixels for some methods.

In our software, we suggest using a completely different method to measure an object's photocentre, which in theory and practice is already more precise than the above mentioned one; and what is important, it is only a little slower. This method is Least Squares Gaussian Fit

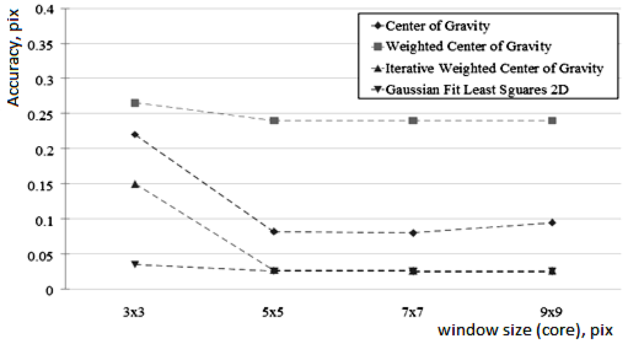

Figure 1: Accuracy of methods for searching photocentres comparing

2D (LSQ2) (Delabie et al., 2015). Its principle is to apply the least squares method to the two-dimensional function of the normal Gaussian distribution. This distribution was selected as a mathematical model because of its comparably high quality of celestial objects profile prediction to other simple functions.

The logarithm of the two-dimensional Gaussian function

$$I(x, y) = I_0 e^{-\left(\frac{(x-x_0)^2}{2\sigma_x^2} + \frac{(y-y_0)^2}{2\sigma_y^2} \right)}$$

was found for the possibility of using LSQ.

Next, after calculating and matching the most valid surface to the profile of each object from the resulting polynomial parameters, the coordinates of the celestial objects were calculated, as well as other parameters including maximum intensity

$$\ln I = x^2 \left(-\frac{1}{2\sigma_x^2} \right) + x \left(\frac{x_0}{\sigma_x^2} \right) + y^2 \left(-\frac{1}{2\sigma_y^2} \right) + y \left(\frac{y_0}{\sigma_y^2} \right) + \left[\ln I_0 - \frac{x_0^2}{2\sigma_x^2} - \frac{y_0^2}{2\sigma_y^2} \right].$$

Among the drawbacks of the method, it is worth noting that it does not work with very faint celestial bodies with the size in the image in total less than 9 pixels. This problem is solved by artificially increasing (stretching) the objects using interpolation (sub-pixel image processing)

$$f = a_0 + a_1 x + a_2 y + a_3 x^2 + a_4 y^2$$

$$\begin{cases} a_0 = \ln I_0 - \dfrac{x_0^2}{2\sigma_x^2} - \dfrac{y_0^2}{2\sigma_y^2} \\ a_1 = \dfrac{x_0}{\sigma_x^2} \\ a_2 = \dfrac{y_0}{\sigma_y^2} \\ a_3 = -\dfrac{1}{2\sigma_x^2} \\ a_4 = -\dfrac{1}{2\sigma_y^2} \end{cases}$$

As a result of the work of our software, coordinates x, y of the photocentres were obtained for each of the objects on each of the images and then they were translated into the equatorial coordinate system. For astrometric reduction, the PMA catalog (Akhmetov et al., 2015) was used as a reference, with a precision of less than 10 mas on epoch 2015 year in position and 2-5 mas/yr in proper motions.

On Fig. 2 stars residuals distribution after reduction into PMA catalogue system is showed; distribution is built by positions during comparing data from present work with using Gausian Fit Least Squares 2D method and data from reference catalogue without any preprocessing of FITS-images (Fig 2.1). On Fig. 2.2 the same one is presented, but, before 'centroiding', the median correction were used. Finally, Fig. 2.3 shows distribution of uncertainties of positions after initial preprocessing including median filtering and convolutional.

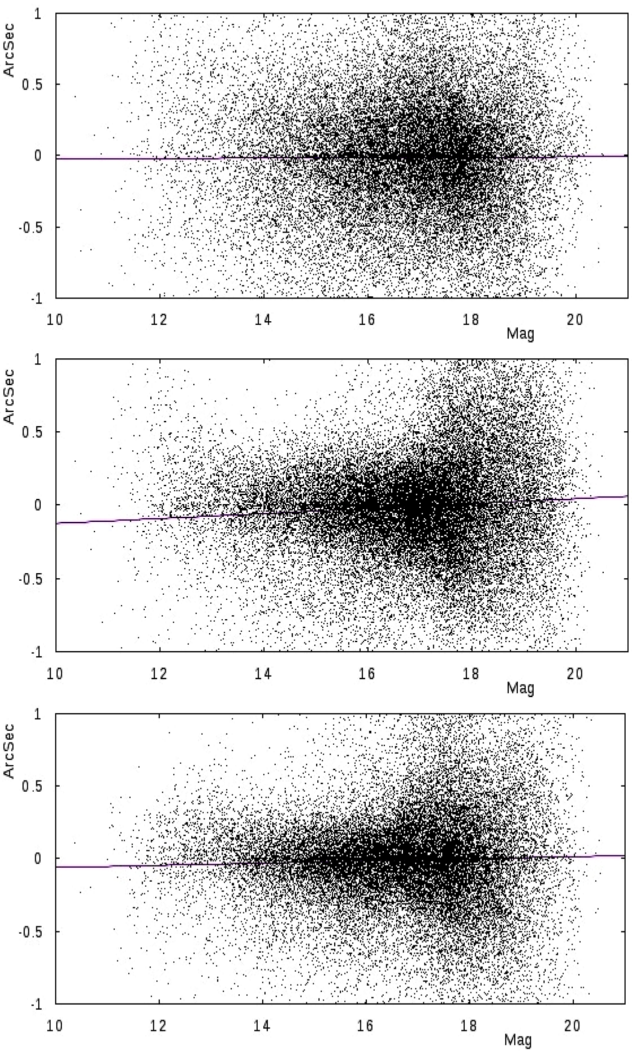

Figure 2: Here are two diagrams that show the deviation of the RA coordinate for SERCJ-602 plate when comparing the PMA catalog data and the data with the images 1) without initial processing, 2) with initial processing: median, 3) with initial processing: median and convolution.

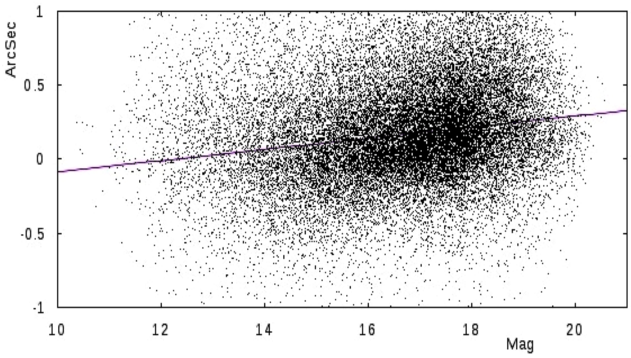

Figure 3: The results compare the SERCJ-602 plate and PMA catalogs by RA.

The mean residuals distribution after reduction into PMA catalogue system obtained in SuperCOSMOS is 630 mas. Using own software package with initial processing, we can calculated photocenter of objects with precision twice better than in SuperCOSMOS. Finally, the mean residuals distribution after reduction into PMA catalogue system after using this software is about 300 mas in both coordinate.

Obviously that obtained precision of positions determination is much better and allow to carry out astrometric reduction on new high level.

4. Conclusion

As result it can be demonstrated that the part of the analyzed data was successfully processed and then the positive results in valuation of the accuracy and acceptable processing speed were obtained.

An alternative method of searching for centroids of Gaussian shaped objects gives results that are much accurate than ones which were used earlier. This suggests that the data of the SCOSMOS plates collection, obtained relatively long ago, can still be useful in the modern approach of their processing.

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