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METHODOLOGY OF PIPELINE DATA REDUCTION FOR ASTROMETRY AND PHOTOMETRY OF A LARGE ARRAY OF CCD OBSERVATIONS

Abstract. We provide the description of the methodology of preliminary data reduction of the CCD observations and following astrometry and photometry analysis of a large number of objects in CCD images during uninterrupted observations, surveys or search campaigns. The result of the method of analysis of a large array of CCD images on the example of the observations of Phaeton asteroid, made on the telescope Zeiss-1000 on the Tien Shan Observatory is presented.

Key words: CCD-observations: data analysis, methods: astrometry, photometry, pipeline for data reduction

Introduction

One of the tasks in Fesenkov Astrophysical Institute (FAI) for 2018-2020 is carrying out CCD observations for the purpose of search and classification of variable stars, as well as long-term observations of individual objects to determine and refine the parameters of their brightness variability. In parallel, there are monitoring observations to search for objects potentially hazardous to Earth (NEOs – near-earth objects), little-known asteroids and comets, as well as the definition and clarification of the physical characteristics of the known NEOs. As a result of such observations, Assy-Turgen (ATO) and Tien Shan (TSO) observatories produce arrays of CCD data, numbering up to several thousand frames per night [1]. Most of these CCD images already have a fairly large field of view (FOV) (32`×32`). In the near future, it is planned to increase the FOV on some instruments to several degrees and the number of objects on one CCD frame, for which it is necessary to obtain photometric and astrometric information can reach several thousand, and the number of frames received during one night will reach several thousand too. It becomes clear that the usual procedure for analyzing CCD images in "manual" mode will require too much time and will lead to an increase in the probability of errors due to the human factor. Variety of observation modes (see "Sorting data") makes this task even more complicated.

Thus, the task of developing a methodology for the automated processing of CCD observations and obtaining astrometric and photometric information for each object on the CCD frame in a format that is most convenient for further analysis becomes quite important in modern observational astrophysics.

Of course, such methods have been developed earlier in other groups and observatories. However, the effectiveness of each specific technique depends on the specificity of the task to which it is directed, as well as the characteristics of the equipment used and observation conditions.

The choice of methods of automatic data analysis in our case is determined by a specific goal — the search for variable stars by analyzing their brightness variability with periods ranged from a few minutes to several hours, using CCDs and EMCCDs with a FOV of not less than 20'×20', with different signal amplification parameters and observations in different wavelengths (a complete list of the parameters used is given in the section "Data sorting").

Methods

As the main tool for search and identification of variable stars, it is supposed to use methods of analysis of light curves obtained on the basis of photometry of stars using CCD observations. Since the survey observations are quite routine, require as long as possible observations in one mode of operation of the equipment, the correct solution will be to automate the observation process itself. Automation makes it possible to use all available observation time as efficiently as possible, to reduce or eliminate errors caused by the human factor, and to utilize budget funds allocated for scientific research more effectively.

Automation of the observation process:

In addition to the above facts, the need to automate the observation process is dictated by the growing number of instruments installed or planned for installation on TSO and ATO, as well as the specifics of their tasks, a variety of requirements for equipment used for different types of observations. In particular, among the various options for only one instrument, with certain equipment one can specify the following parameters: the object of observation, its priority, visibility conditions, the required duration of observations, a combination of filters, exposure values, the need to obtain calibration frames and frames of standard fields, etc. The complexity of the observation process increases nonlinearly if there is the necessity to replace equipment for observation during one night of different objects.

Optimization of the process of analysis of observations is not limited only to the automation of the observation process, but also includes such steps as data management (sorting data and storing it in the databases), preparation for the analysis and the analysis itself with the output of the results in a user-friendly format. These steps are shown schematically in Figure 1.

The task of automating the observation process is successfully solved in FAI and a detailed description of its implementation will be presented in a separate publication.

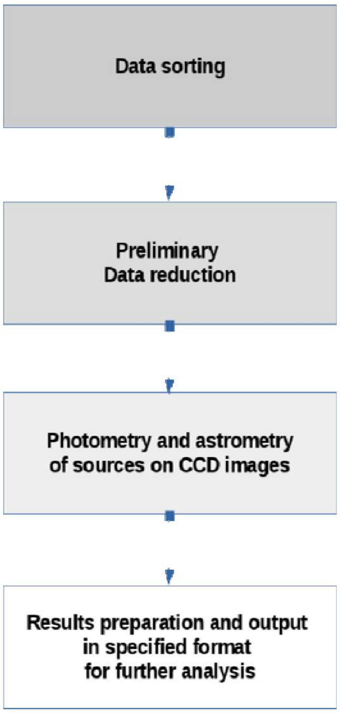

Figure 1 - Sequence of the main steps in the analysis of CCD observations

Data sorting:

For the effective use of the obtained observations and the convenience of their analysis by the scientific community, the observations must be appropriately ordered (sorted) and stored in the database.

The process of automatic sorting of observations significantly simplifies the subsequent procedure of their analysis and can significantly minimize the impact of errors due to the human factor. One of the possible algorithms for sorting CCD observation data, based on the analysis of information in fits-header, is implemented by us in the python environment and is shown in Figure 2. In particular, the presented technique automatically sorts data into directories with certain observation dates. In each such directory, the corresponding subdirectories are created designated by the object name (for example, by catalog number), the filter used, etc., as shown in Figure 2. This sorting not only simplifies subsequent data analysis, but also greatly facilitates the observation process itself, since the observer does not need to track the uniqueness of the assigned ID (or file name) of the CCD frame, but rather correctly prepare the observation plan for the current session, and the relevant information is automatically entered through certain keys in the header of the fits file. Simultaneously with the sorting of the observations, CCD images can be checked, for example, for errors of tracking, temperature stability, while it is possible to automatically generate a report on the statistics of observations and the necessary request for calibration images if some of them are not found.

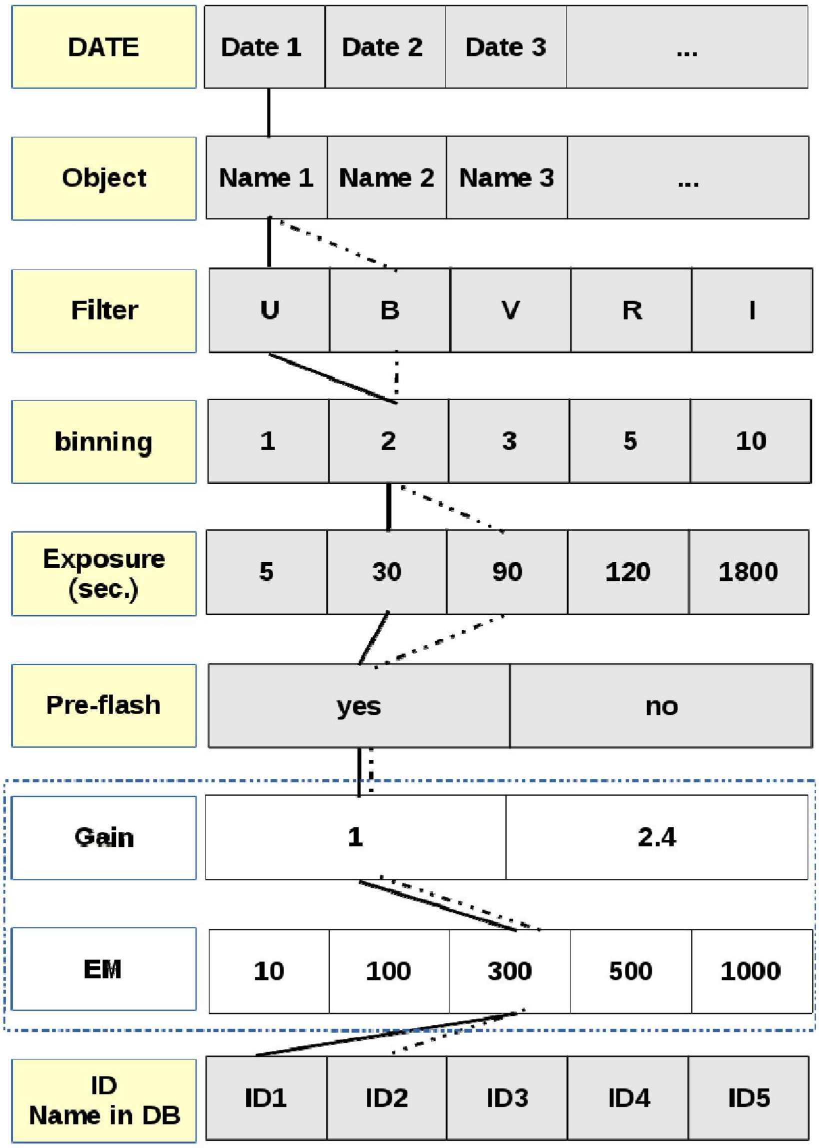

Figure 2 - Automatic data sorting of the CCD frames based on relevant parameters of the observations. Solid and dashed lines show examples of parameter combinations. The parameters Gain and EM correspond to observations performed with the use of EMCCD and are not used for the conventional CCD

Preliminary data reduction:

The next step in the preparation of observations for further analysis is to take into account instrumental systematic noise in CCD images. We will not dwell on this issue, those interested can get acquainted with it in detail in the [2]. The systematic noise includes the dark current, the bias offset and the unevenness of sensitivity on the field of the CCD. To minimize random noise in the accounting of systematic error, the corresponding calibration frames should be averaged over a sufficient number of images (usually not less than 10). The IRAF package is used as the main tool for the analysis of astronomical data of CCD observations (http://iraf.noao.edu/). Averaged CCD frames of bias (MasterBias) can be obtained by zerocombine procedure (iraf.imred.ccdred), a dark current (MasterDark) is obtained by darkcombine (iraf.imred.ccdred) routine. MasterDark must be taken for each image obtained with combinations indicated in Figure 2 (except for the selection of filters). MasterBias and MasterDark are additive noises and should be subtracted from the CCD image of the object (respectively, MasterBias is first subtracted from MasterDark), and the heterogeneity of the sensitivity along the CCD image is a multiplicative component, so CCD image of the object should be divided by it. The averaged CCD frame of the flat field (MasterFlat) must be obtained for each filter in which the object was observed and correctly corrected for corresponding MasterDark. To obtain MasterFlat one may use the flatcombine procedure (iraf.imred.ccdred). After that the MasterBias, MasterFlat and MasterDark are used in preliminary data reduction using ccdproc procedure (iraf.imred.ccdred).

Pipeline method for automatic photometry of objects on CCD frames:

Since our main task is to search for variable stars by analyzing the light curves, the technique should perform the following steps: 1) automatically assign the equatorial coordinate grid to the CCD frame, 2) detect all sources on the FOV of the CCD frame, 3) determine among them the stars belong to different catalogs, 4) conduct aperture and PSF-photometry and 5) output the results in a format convenient for further analysis.

For clarity and ease of understanding of the whole process its flowchart is shown in Figure 3.

As the environment for method implementation, the combination of the Linux operating system with a high-level language python was chosen. This choice is made for several reasons. First, both Linux and python are open source (the standard public license, GNU GPL). Secondly, python is one of the most dynamically developing high-level languages, it is quite simple and provides ample opportunities to attract a large number of people, including students and post-graduates. Third, an IRAF package is integrated into the python environment (http://www.stsci.edu/institute/software_hardware/pyraf). The algorithms and methods of this package have been repeatedly tested, well documented and integrated into many modern data analysis packages of CCD observations. All iraf functions and libraries are available and can be directly imported into the python environment.

To date, the python community has developed a large number of applications for working with digital images, analysis of astronomical catalogs, presentation of graphical and other information directly in a format suitable for publication or use by other applications. The most popular python platform for scientific data analysis is Anaconda, developed by Continuum Analytics (https://www.anaconda.com/). We use this platform to install the AstroConda channel with all relevant packages (http://astroconda.readthedocs.io/en/latest/index.html). The whole installation and configuration process is quite simple.

Let us now examine in detail each of the steps shown in Figure 3. At the beginning of the process, a list of CCD frames that have been preprocessed is formed. To do this, one uses the getcwd and listdir procedures imported from iraf.os in python. Further, for the convenience, we will denote by ← the process of importing the appropriate packages and methods into python. At this stage, the procedure checks the existence of appropriate directories to save the results and the corresponding log-file (path.exists, makedirs ← iraf.os).

The results of observations are saved in the fits format [3], in the header of which all parameters of observations are listed. Working with fits-files is carried out through astropy package.io.fits. The header of the fits file is analyzed to determine such parameters as the coordinates of the observatory (astropy [4]), the size of the CCD frame and FOV of the CCD (in arcminutes), the focal length f in mm, the pixel size in μm, the image scale in arcsec/pixel. For the analysis of observations obtained at different epochs, especially for the analysis of light curves of variable stars, it is desirable to use barycentric Julian date. This is calculated using barycentric correction (time ← astropy).

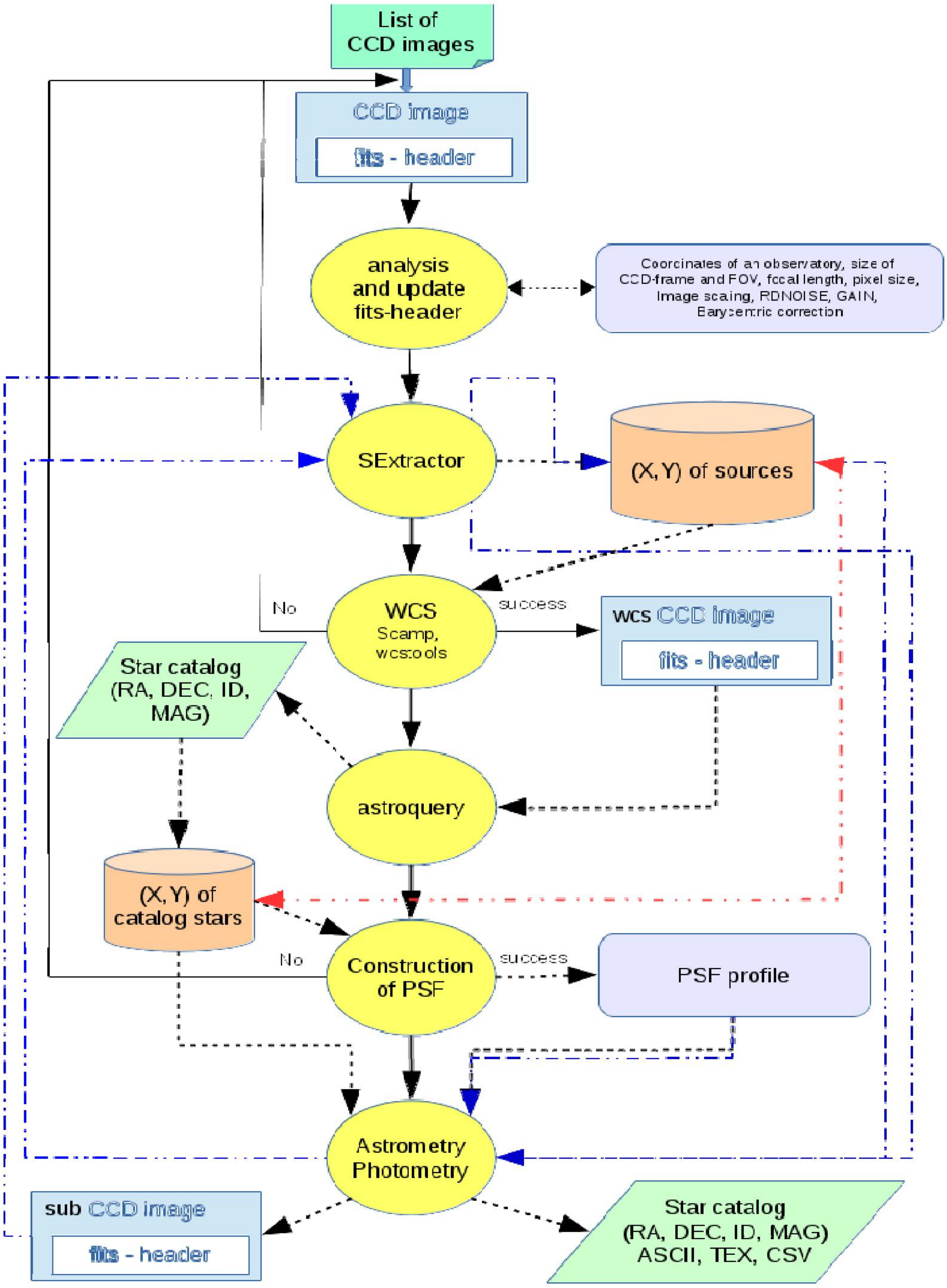

Figure 3 - Flowchart of the procedure of automatic aperture- and PSF-photometry and astrometry of all sources detected in the field of CCD image

The next step is to automatically assign the equatorial world coordinate system (wcs) to the CCD frame. This task can be performed using two methods: wcstools [5,6,7] or scamp [8]. To do this, in the fits header, in addition to such parameters as the image center, image scale, the preliminary values of the main parameters of wcs are set, and the geometry of the frame is determined (that is, the need to invert and rotate the CCD frame). The necessary information for wcstools and scamp also includes a list of objects, or rather the coordinates (X, Y) of the sources on the CCD frame. The SExtractor package [9] is used to detect these sources. The type of the output catalog for the correct operation of the scamp must be FITS_LDAC (Leiden Data Analysis Center). Determined location of the sources, that is, their coordinates (X, Y), and the position of the center of the frame in the second equatorial coordinates system for the epoch of 2000 are used to assign the wcs-coordinates. The accuracy of the plate solution procedure can be estimated from the output figure of combined residuals that is automatically generated by the scamp task. An example of a residual map is shown in Figure 4. The X and Y axes, respectively, show the coordinate differences between the catalog values and the values obtained from the plate solution, and the corresponding difference distributions.

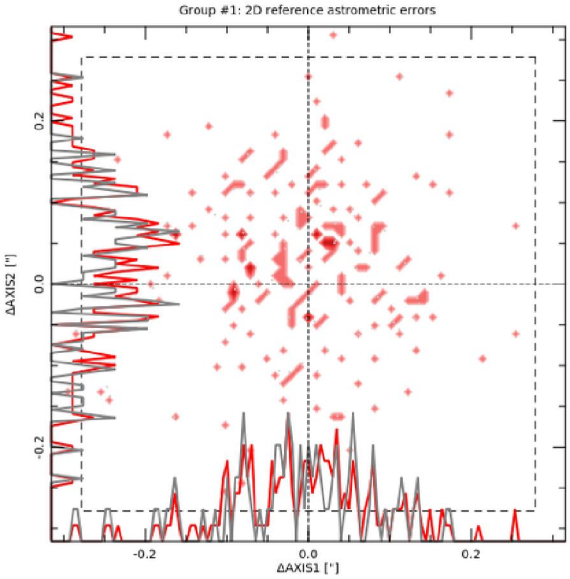

Figure 4 - An example of a 2D map of the coordinate residuals from the results of the scamp procedure, using the CCD-observations with FOV of 19’×19’, obtained on the Zeiss-1000, TSO (November 2017)

In the case of a success of the wcs-procedure, corresponding CCD frame with updated fits header is passed further to search for catalog stars on the FOV.

Catalogs query to search for known stars:

The next step of the methodology is the identification of stars on the FOV of the CCD-frame listed in various catalogs. For example, these can be photometric standard catalogs or variable star catalogs. In the former case, these stars can be used to convert instrumental stellar magnitudes into a standard photometric system, and in the latter case, identified stars can be excluded from further analysis as variables or suspected variables. Astroquery package [10] (Vizier ← astroquery.vizier) allow one to automatically identify stars of the catalog of particular interest from the Vizier database. In our implementation of the data analysis process URAT1 [11], UCAC4 [12] or 2MASS [13] catalogs are used. The values of the magnitudes in the ugriz system (the photometric system of the SDSS) converted into the UBVRI system, which is used on TSO. The following conversion equations are used for this purpose [14]:

$$B - g = (0.313 \pm 0.003) \cdot (g - r) + (0.291 \pm 0.002)$$
$$V - g = (-0.565 \pm 0.001) \cdot (g - r) - (0.016 \pm 0.001)$$
$$V - I = (0.675 \pm 0.002) \cdot (g - i) + (0.364 \pm 0.002),\ \ if\ \ g - i \leq 2.1$$
$$V - I = (1.11 \pm 0.02) \cdot (g - i) - (0.52 \pm 0.05),\ \ if\ \ g - i > 2.1$$
$$R - r = (-0.153 \pm 0.003) \cdot (r - i) - (0.117 \pm 0.003)$$
$$R - I = (0.93 \pm 0.005) \cdot (r - i) + (0.259 \pm 0.002)$$

The equatorial coordinates of the detected stars in the catalog are transformed to the (X, Y) coordinates of the position on the CCD frame using astLib library (astWCS ← astLib). The positions of stars are checked for proximity to the edges of the CCD frame and are excluded from the analysis if they are located too close to the edge of the FOV (usually less than the width of the star profile). The resulting catalog of stars tabulated in a convenient from using astropy.table (Table, Column ← astropy.table) and is submitted to the procedure to build a PSF profile for PSF photometry of all sources detected on the frame.

There are several reasons why we chose this method of building PSF-profile. First, we use a star catalog, and not just the detected sources in the field of CCD frames, among which could be random sources. Secondly, we, simultaneously to construction of the PSF profile, conduct photometry of catalog stars, which allows us, in the future, to carry out transformation into a standard photometric system, if there were no observations of the standard fields carried out for some reason. This is particularly useful if observations are to be made in uninterrupted regime. Third, the subsequent subtraction of catalog stars allows to detect and conduct photometry of stars that are not included in the catalogs. Such stars are the main targets of observation campaigns and surveys.

To automatically build a proper PSF profile one should be sure that the profiles of the selected stars are far enough from the edge of the CCD frame and do not overlap with each other. We use the following criteria for the selection of PSF stars:

$$3 \cdot R_{PSF} < X < N_{pix} - 3 \cdot R_{PSF} \text{ and } 3 \cdot R_{PSF} < Y < N_{pix} - 3 \cdot R_{PSF},$$

$$FWHM_{PSF} \cdot scale/2 < r_{ij} < R_{PSF} \cdot 2 \cdot scale,$$

where $r_{ij} = \sqrt{\Delta x^2 + \Delta y^2}$ and $\Delta x, \Delta y$ - the mutual distance between the centeroids of the stars. Here $N_{pix} = NAXIS1$ - size of the CCD frame in pixels, $R_{PSF} = 4 \cdot FWHM_{PSF} - 1$ - radius of the PSF-profile, $FWHM_{PSF} = \frac{seeing}{scale} + 0.1$ - preliminary estimation of full width at half maximum of the PSF-profile with $seeing = 2''.5$, which is determined by astroclimate of an observatory. The parameter $scale = \frac{\mu m}{f} \cdot 206.265$ - is image scale in arcseconds per pixel, where $\mu m = XPIXSZ$ - physical size of the pixel in micrometers, $f = FOCALLEN$ - equivalent focal length of the telescope in mm. After star selection procedure using preliminary estimation of the parameters the value of $FWHM_{PSF}$ is refined automatically using radial profile fitting procedure radprof of the IRAF applied to selected stars. The total number of PSF stars selected according to these criteria usually does not exceed 25. Obtained refined profile parameters are used for the specification of the parameters for the photometry procedure. Photometric aperture $Ap = 5 \cdot \sigma$ where σ of the Gauss profile related to $FWHM_{PSF}$ as $\sigma = \frac{FWHM_{PSF}}{2\sqrt{2\ln(2)}}$, inner sky radius for sky background estimation is $R^{sky}_{inner} = 6 \cdot \sigma$ and corresponding outer sky radius is $R^{sky}_{outer} = R^{sky}_{inner} + 5.0$. Radius of the PSF-prifile used for fitting is $R_{fit} = FWHM_{PSF} + 0.75$.

The selection of the PSF profile function can be automatic or user-defined. In our implementation, the Moffat profile with β=2.5 [15] is used, and if the construction is unsuccessful, the profile "penny2" is used (a complex profile whose kernel is described by the Gauss function, and the wings of the distribution are described by the Lorentz function with the parameter β=1, while the Gauss and Lorentz functions can be inclined in different directions), which showed the best result. To normalize the PSF profile, first the daophot.phot procedure is used to estimate flux value using aperture photometry. Then the daophot.pstselect procedure selects stars to build a PSF profile and finally daophot.psf builds the PSF profile.

If the PSF profile is successfully built, it is passed to the next stage of processing. If for some reason the PSF profile cannot be built, the program proceeds to the next CCD frame.

Catalog stars subtracting from the CCD frame and search for new objects:

The next step is photometry of catalog stars and their subsequent subtraction from the field of CCD frame. To do this, the aperture photometry of all stars of the catalog is carried out again by the phot.daophot procedure. The resulting aperture photometry values, PSF profile, and the corresponding source coordinates are used for the PSF photometry using allstar.daophot task. As a result, in addition to the photometry results, we obtain images with subtracted catalog stars for which photometry was successfully performed. These images are used to search for new sources (SExtractor) that are not included in the catalog and which are of our main interest. After that, a generalized list of objects is formed. At this point, one can recalculate the PSF profile again to check the overlap of the star profiles. Then the PSF-photometry is performed simultaneously for all stars in the combined list by allstar.daophot procedure. This stage is shown in Figure 3 by a blue dashed line.

The resulting CCD frame with all detected and successfully passed photometry stars subtracted should ideally shows a field with background noise. An example of sequential subtraction of processed stars is shown in Figure 5.

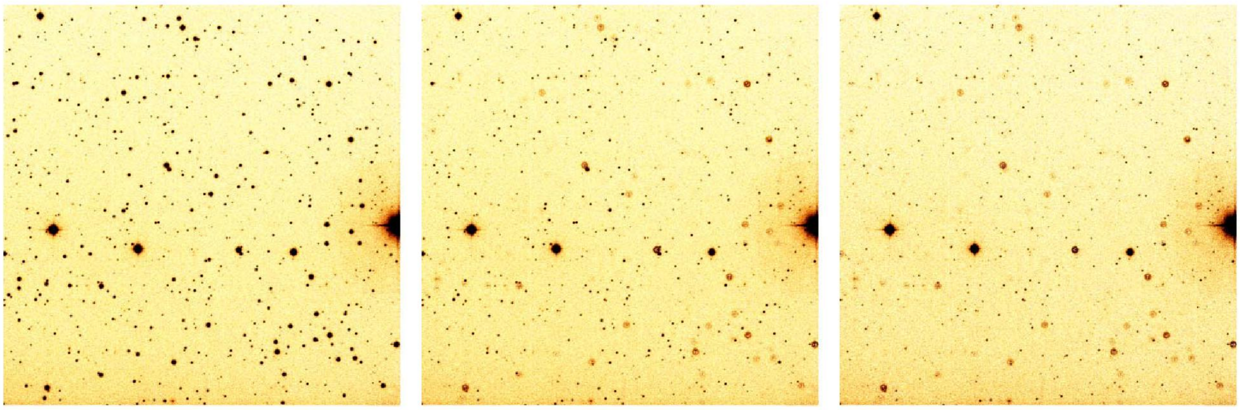

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Figure 5 - CCD images with the sequential subtraction of stars: a) the original CCD image, b) after photometry and subtraction of the catalog stars, c) after photometry and subtraction of sources not included in the catalog. The remaining stars on the field were overexposed and excluded from the analysis process

Output the results of the analysis:

For the convenience of further analysis of the obtained results, using them directly for publication or exchange between interested groups, they given in the form of tabular values in the conventional text format, and in the format of csv and tex. These tables are automatically generated separately for catalog stars and for objects that are not included in catalogs. Tables for catalog stars contain the following information: catalog number (recno), the coordinates of the object in the catalog in fractions of degrees (RAJ2000, DEJ2000), the values of magnitudes in the catalog (Bmag, Vmag, Rmag, Imag), the coordinates of the object in the catalog in the format h:m:s and d:m:s (RA and DEC), their magnitude in a certain filter (V_Johnson), corresponding error of magnitude (errV_Johnson), the observed values of the coordinates in the format h:m:s, d:m:s (RA_obs, DEC_obs), barycentric Julian date (OBS-TIME) and the air mass at the time of the observations (AIRMASS). The tables for objects not included in the catalogs contain the following information: number of internal (local) catalog (recno), magnitude values in a certain filter (V_Johnson), corresponding magnitude error (errV_Johnson), observed coordinate values in the format h:m:s, d:m:s (RA_obs, DEC_obs), barycentric Julian date (OBS-time) and air mass at the time of observations (AIRMASS).

Results

The described method is tested on observations of the asteroid Phaeton that were obtained on the Zeiss-1000 (TSO) in the period from 16.11.2017 until 22.11.2017. In total, more than 280 CCD images were obtained in each of the three BVR filters. That is, the total number of images is more than 800. Several dozens of catalog stars are identified on the field of each CCD image and, therefore, the number of photometric estimates and astrometric measurements can reach several tens of thousands. If we take into account the registered sources that are not included in the catalogs (which are of the greatest interest for us), the number of photometric measurements for this particular example is several hundred thousand! However, the whole process of photometry of the whole array of observations in automatic mode takes only a few hours.

The developed technique of automated photometry of all sources on the field of the CCD frame can be used to search for objects with large proper motion (for example, asteroids and other small bodies of the solar system).

As an example, the result of the methodology applied to the observation of the asteroid Phaethon (3200) is shown in Figure 6. This figure shows a plot of 10'×10' FOV with the result of automatic astrometry and photometry of all objects observed in 19.11.2017 on the Zeiss-1000 telescope (TSO). The size of the marks corresponds to the instrumental stellar magnitude. In addition to the main object of interest (the Phaeton), two known asteroids are also visible on the field (230273, 45156). When one constructs such a map, catalog stars identified by a unique number are displayed with colored symbols, depending on the magnitude of the stars in the three filters. The values of stellar magnitudes and positions of these stars are automatically saved as tables in three formats (text, csv, tex) for each of the stars of the catalog separately and for each of the filters in which observations were carried out. Information on other objects of interest to the user can be obtained, for example, by selecting the appropriate area on the map shown in Figure 6. The resulting tables are used to construct and analyze the light curves. The results of this analysis will be presented in a separate publication.

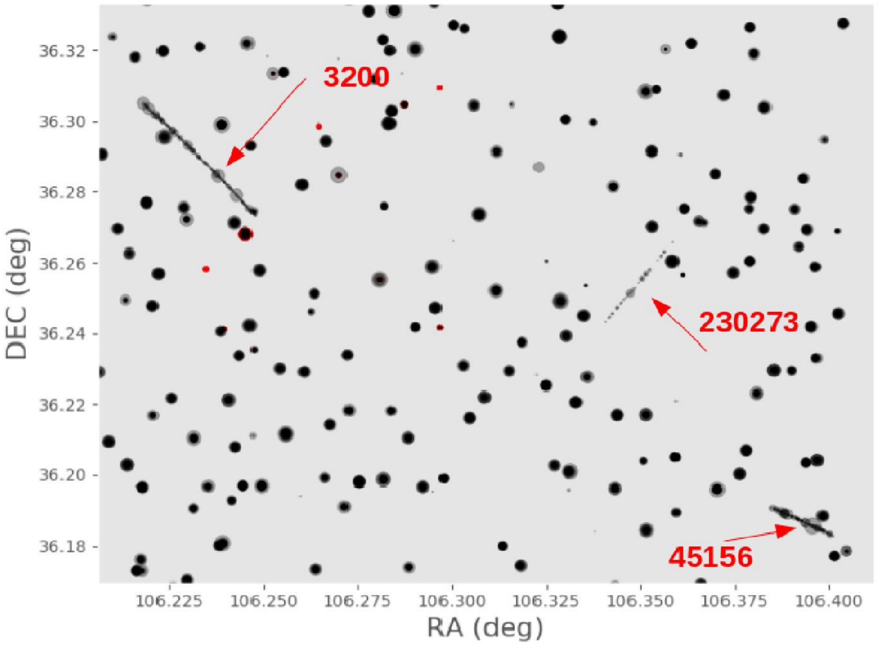

Figure 6 - The results of the automatic photometry and astrometry of the CCD-observations obtained on the Zeiss-1000 (TSO). Shown is field of size ~ 10'×10', where one can identify the tracks of the three asteroids (indicated by arrows and number)

Discussion

Conducting survey and search observations to detect transients, fast evolved processes, monitoring for variable stars, etc. on medium and small aperture instruments (from 50 cm to 1 meter) with a sufficiently large FOV involves obtaining a large array of observations. Especially if EMCCD is used as an instrument in time-domain astrophysics. In addition, the availability of the results of various sky surveys in the form of databases can significantly improve the efficiency of searching for new objects, information about which is not available in catalogs, or quickly respond to the need for alert and followup observations of high-priority objects. This makes the task of fast and robust processing and analysis of observational data particularly relevant.

The methodology described in this article was implemented under the Linux operating system based on the python high-level language and uses generally accepted and proven algorithms for data analysis (whose implementations are freely available).

The work on improving the methodology continues. In particular, it is necessary to develop criteria for updating the parameters of procedures for detection of faint objects on a FOV, to consider the possibility of building a PSF profile for the particular instrument, which should not only improve the quality of the results of PSF-photometry, but also reduce the processing time. Another important problem to be solved is an implementation of methods of extended object photometry including tracks of objects observed at different regimes of telescope tracking, as well as photometry of extended objects (galaxies, nebulae).

In conclusion, we should note some possible sources of errors in photometry and astrometry using the developed methodology. First, it is assumed that the PSF profile remains constant throughout the entire observation session, which may not be the case for observations in highly changing weather conditions, inaccuracies in the telescope tracking (wind, auto-guiding failure, etc.). As a result of the incorrect description of the true stellar profile on the images, there will be some remnants after subtracting the stars which can be incorrectly interpreted as additional sources. This ultimately leads to errors in photometry. Second, it is assumed that the dependence of the PSF profile on the CCD frame is also constant or changes linearly. If this requirement is not met, it can also lead to errors in the photometry of stars and the detection of false sources. To determine the valid regimes of adequate performance and assessment of the domain of application of the methodology we should test it on artificial data generated with different noise levels and different complexity of the field (density of sources, the variability of the PSF-profile stars across the field of the CCD frame, etc.).

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REFERENCES

[1] Serebryanskiy A., Krugov M., Komarov A., Usoltseva L., Akniyazov Ch. The first results of observations on the new optical system based on RC500 telescope and EMCCD (Electron Multiplying Charge-Coupled Device) at Assy-Turgen observatory in Kazakhstan // Solar system research. 2018. (in press).

[2] Howell S. B. Handbook of CCD astronomy // Cambridge University Press the Edinburgh Building, Cambridge cb2 2ru, UK Published in the United States of America by Cambridge University Press, New York. 2006.

[3] Wells, D. C.; Greisen, E. W.; Harten, R. H. (1981) FITS - a Flexible Image Transport System // Astronomy and Astrophysics Supplement. 1981. v. 44. P. 363.

[4] Astropy collaboration Astropy: A community Python package for astronomy // Astronomy & Astrophysics. 2013. V.558, id.A33. - P.9. - DOI: 10.1051/0004-6361/201322068.

[5] Mink, D. // ASP Conf. Ser. 1997. V.125. - ADASS VI, ed. G. Hunt & H. E. Payne (San Francisco: ASP). P.249.

[6] Mink, D. // ASP Conf. Ser. 1999. V.172. ADASS VIII, ed. D. M. Mehringer, R. L. Plante, & D. A. Roberts (San Francisco: ASP). P.498.

[7] Mink, D. // ASP Conf. Ser. 2002. V.281. - ADASS XI, ed. D. A. Bohlender, D. Durand, & T. H. Handley (San Francisco: ASP). P.169.

[8] Bertin, E. Automatic Astrometric and Photometric Calibration with SCAMP, Software for Calibrating AstroMetry and Photometry // Astronomical Data Analysis Software and Systems XV ASP Conference Series. – 2006. - V.351, Proceedings of the Conference Held 2-5 October 2005 in San Lorenzo de El Escorial, Spain. Edited by Carlos Gabriel, Christophe Arviset, Daniel Ponz, and Enrique Solano. San Francisco: Astronomical Society of the Pacific. P.112.

[9] Bertin, E. SExtractor: Software for source extraction // Astronomy and Astrophysics Supplement. 1996. V.117. P. 393-404.

[10] Jenness,T., Robitaille, Th., Tollerud, E., Mumford, S., Cruz, K. Python in Astronomy // Proceedings of the conference held 21-25 March, 2016 at the University of Washington eScience Institute in Seattle, WA, USA. 2016. id.34.

[11] Zacharias, N., Finch, C., Subasavage, J., Bredthauer, G., Crockett, C., Divittorio, M., Ferguson, E., Harris, F., Harris, H., Henden, A., Kilian, C., Munn, J., Rafferty, T., Rhodes, A., Schultheiss, M., Tilleman, T., Wieder, G. The First U.S. Naval Observatory Robotic Astrometric Telescope Catalog // The Astronomical Journal. 2015. V.150, Issue 4, article id. 101.

[12] Zacharias, N., Finch, C. T., Girard, T. M., Henden, A., Bartlett, J. L., Monet, D. G., Zacharias, M. I. The Fourth US Naval Observatory CCD Astrograph Catalog (UCAC4) // The Astronomical Journal. 2013. V.145, Issue 2, article id. 44

[13] Cutri, R.M., Skrutskie, M.F., van Dyk, S., Beichman, C.A., Carpenter, J.M., Chester, T., Cambresy, L., Evans, T., Fowler, J., Gizis, J., Howard, E., Huchra, J., Jarrett, T., Kopan, E.L., Kirkpatrick, J.D., Light, R.M., Marsh, K.A., McCallon, H., Schneider, S., Stiening, R., Sykes, M., Weinberg, M., Wheaton, W.A., Wheelock, S., Zacarias, N. VizieR Online Data Catalog: 2MASS All-Sky Catalog of Point Sources (Cutri+ 2003) // VizieR Online Data Catalog. 2003. 2246.

[14] Jordi, K., Grebel, E. K., Ammon, K. Empirical color transformations between SDSS photometry and other photometric systems // Astronomy and Astrophysics. 2006. V.460, Issue 1. - P.339-347, DOI: 10.1051/0004-6361:20066082.

[15] Trujillo, I., Aguerri, J. A. L., Cepa, J., Gutie´rrez, C. M. The effects of seeing on Se´rsic profiles – II. The Moffat PSF // Monthly Notices of the Royal Astronomical Society. 2001. V.328, Issue 3. P.977-985, DOI: 10.1046/j.1365-8711.2001.04937.x

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ҮЛКЕН АУҚЫМДАҒЫ ЗБА-БАҚЫЛАУ МӘЛІМЕТТЕРІН ФОТОМЕТРЛЕУ ЖӘНЕ АҒЫМДЫҚ АСТРОМЕТРИЯНЫҢ ӘДІСНАМАСЫ

Аннотация. Іздеу кампаниялары немесе аспанды шолуда ұзақ уақыт бақылау жүргізгенде, ЗБА-суреттердегі объектілер саны максималды болғанда және оның астрометриялық және фотометрлік зерттеулерін жүргізудің ЗБА-бақылауларының алдын-ала өңдеу процесінің өңделген әдіснамасы берілген. Цейсс-1000 (ТШАО) телескобында астероид Фаэтонның үлен ауқымды бақылау мәліметтерінің талдау әдіснамасының нәтижелері көрсетілген.

Тірек сөздер: ЗБА-бақылаулары: мәліметтердің талдаулары, әдіснама: астрометрия, фотометрия, ағымдық мәліметтерді өңдеу.

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МЕТОДИКА ПОТОКОВОЙ АСТРОМЕТРИИ И ФОТОМЕТРИИ БОЛЬШОГО МАССИВА ПЗС-НАБЛЮДЕНИЙ

Аннотация. Дано описание разработанной методики процесса предварительной обработки ПЗС-наблюдений, последующей астрометрии и фотометрии максимального количества объектов на ПЗС изображениях, которые получаются при продолжительных наблюдениях, обзорах неба или поисковых кампаниях. Показан результат работы методики анализа большого массива ПЗС-изображений на примере данных наблюдений астероида Фаэтон, выполненных на телескопе Цейсс-1000 (ТШАО).

Ключевые слова: ПЗС-наблюдения: анализ данных, методы: астрометрия, фотометрия, потоковая обработка данных.

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