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THE ASTROMETRIC AND PHOTOMETRIC RESULTS OF DIGITIZED PLATES ON EPSON EXPRESSION 10000XL SCANNER WITH DIFFERENT RESOLUTIONS

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ABSTRACT. This work was done to assess the accuracy of the plate processing method and to study in detail the Epson Expression 10000XL scanner, which is used to digitize the FON-Kitab astronomical plates from the photographic archive collection of the Ulugh Beg Astronomical Institute (UBAI) of the Uzbekistan Academy of Sciences. The glass archive of the UBAI has about 15 thousand photographic plates with images of various space objects. To process the plates the specially developed software in the LINUX/MIDAS/ROMAFOT was used. From comparing the results of processing digitized files with grayscale 8 and 16 bits, an assessment of the accuracy of the developed method for determining rectangular coordinates and photometry was made. The Epson Expression 10000XL flatbed scanner together with developed software can be used to digitize and process the astronegatives and obtain characteristics of objects (high, medium and moderate brightness) with an internal accuracy better than 0.05″ and 0.015^m for equatorial coordinates and B-magnitudes, respectively. To assess the repeatability of astrometric and photometric errors of the scanner, six consecutive scans of one plate with 600, 900, 1200, 1500, 1800, 2100, 2400 and 2540 dpi spatial separations were processed. The average accuracies of measurements were $\sigma_{\alpha\delta}$=0.07″ for the equatorial coordinates and σ_m=0.13^m for *B*-magnitudes. The results of the experiments showed that a scan mode with a spatial resolution of 1200 dpi is the best option for plate digitization. Higher resolution scanning modes require a significant increase of digitizing and processing times of a plate, but they do not affect on an accuracy of the obtained results.

Keywords: stellar catalogs, scanning, processing of digitized photographic plates, astrometry, photometry, UBV system, stellar B-magnitudes.

АНОТАЦІЯ. Робота виконана з метою оцінки точності методу обробки платівок та детального дослідження сканера Epson Expression 10000XL, за допомогою якого оцифровуються платівки ФОН-Кітаб із колекції склотеки Астрономічного інституту Академії наук Республіки Узбекистан. У скляному архіві Астрономічного інституту є близько 15 тис. астроплатівок із зображеннями різних космічних об'єктів. Для обробки астроплатівок використовується програмне забезпечення, створене в програмному середовищі LINUX/MIDAS/ROMAFOT. Із порівняння результатів обробки оцифрованих файлів з градаціями сірого 8 та 16 біт зроблено оцінку точності розробленого методу визначення прямокутних координат та фотометричних величин. Планшетний сканер Epson Expression 10000XL разом з розробленим програмним забезпеченням дозволяє оцифровувати і обробляти платівки та отримувати характеристики об'єктів (високої, середньої та помірної яскравостей) з внутрішньою похибкою не гірше 0.05″ і 0.015^m для екваторіальних координат та величин B відповідно. Для оцінки повторюваності астрометричних та фотометричних похибок сканера було оброблено по шість послідовних сканів однієї платівки з просторовим розділенням 600, 900, 1200, 1500, 1800, 2100, 2400 та 2540 dpi. Середня точність вимірювань становила $\sigma_{\alpha\delta}$=0,07″ для екваторіальних координат та σ_m=$0,13^m$ для зоряних B-величин. Результати досліджень показали, що режим сканування з просторовою роздільною здатністю 1200 dpi - найкращий варіант для оцифрування платівок. Режими з більшою роздільною здатністю сканування потребують значного збільшення як часу сканування, так і часу обробки сканів і не приводять до суттєвого покращення точності для отримуваних результатів.

Ключові слова: зоряні каталоги, сканування, обробка оцифрованих платівок, астрометрія, фотометрія, UBV система, зоряні величини B.

1. Introduction

Astronegatives which were obtained under the project Photographic Sky Survey (PSS, in Russian – FON) [Andruk, 2017b; Pakuliak, 2016] using Zeiss Dual Astrograph, are contained main part of glass archive of the Astronomical Institute of the Uzbekistan Academy of Sciences (UBAI). Fourfold overlap of sky method was used for all astronegatives

in zones from -20 ° to + 28 ° by DEC (shifting to 2 degrees by RA). In addition, the archive contains observational images of following projects: galaxies and nebulas, open and globular star clusters, Solar system bodies (planets, comets, asteroids) [Shatokhina, 2018; Yizhakevych, 2018], close open clusters and star-formation regions, variable stars, radio-source regions, and others.

In present, the astronegatives are being digitized and cataloged in international format WFPDB (Wide-Field Plate Database). For digitization, the Epson Expression 10000XL flatbed scanner which is used in many observatories of the world is used [Andruk, 2015; Eglitis, 2017; Muminov, 2017; Protsyuk, 2014]. In this paper, it is presented method and processing results of digitized images which were scanned with different resolutions (600, 900, 1200, 1500, 1800, 2100, 2400 and 2540 dpi).

2. Estimation of processing accuracy in the MIDAS/ROMAFOT software environment

The digitized images were obtained in TIF format with 16-bit grayscale using the flatbed scanner Epson Expression 10000XL. For the processing in the MIDAS/ROMAFOT package, all digitized images were converted into a FIT format, and the number of color gradations can be arbitrary. Depending on the grayscale gradations (16-bit or 8-bit), file sizes differ up to twice and it affects the amount of disc space to store them. Since the files were converted from 16-bit (frame A) to 8-bit (frame B) the estimation of possible losses of precisions for astrometric and photometric determinations a comparison of the processing results was made. Frames A and B with spatial resolution were obtained for plate No. 399, exposed in the B-band of FON project. Objects on the astronegative were registered with two exposures: long and short exposures are 28 and 1 minute, respectively. After processing of both frames for each object in the MIDAS/ROMAFOT software environment, we have their astrometric (rectangular *X, Y* coordinates) and photometric characteristics (instrumental magnitudes *m*, diameters of the objects *f* (FWHM) on the plate and intensity values I_c in the center of the image). For the study the stars in long-exposure which have pair stars in short-exposure were selected, the amount of them was n=3147 [Andruk, 2012]. Results of comparison of differences between calculated rectangular coordinates, instrumental magnitudes and diameter of the objects are presented in Fig. 1. The upper part of Fig. 1 shows the differences between the calculated values for astrometric (1a, 1b) and photometric (1c, 1d) characteristics of stars for the A and B frames, according to their rectangular coordinates (*X*, *Y*), instrumental magnitudes (*m*) and objects' diameters (*f*). Bigger and smaller values of *m* and *f* correspond to bright and faint stars. The root-mean-square errors *rms* of the difference between the first and second methods of digitization are indicated. At the bottom of the figure (1a, 1b, 1c, 1d), these differences are shown as real (continuous lines) and theoretical (dashed lines) distribution functions versus the corresponding intervals of Δx, Δy, Δm, and Δf. The length of interval (0.4 values of standard deviations) and determined X^2 values are presented on the bottom of the figure. The data were obtained for the stars in the range of $B=7^m \div 14^m$. The limited

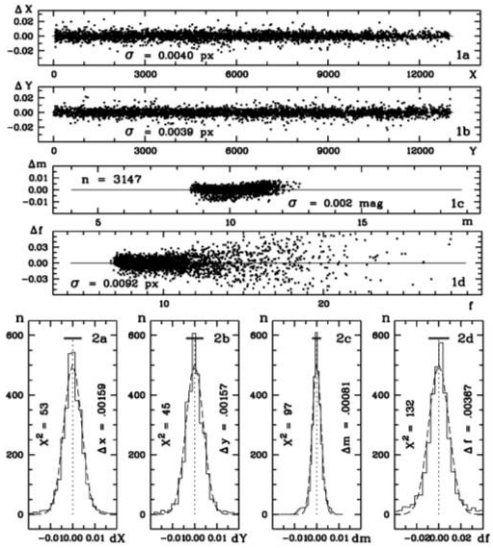

Figure 1: The differences of astrometric and photometric results between A (8-bit) and B (16-bit) frames.

magnitude was $B=17.5^m$ for long exposure stars. The errors increase twice for extremely faint stars. Since *rms* less than 0.004 px and 0.002^m for the rectangular coordinates and stellar magnitudes, it can be concluded that the digitization could be made with 8-bit color depth without losing the accuracy of the results.

3. Repeatability of the results of scanning and scanner errors

Six consecutive scans of the same plate were processed for assessing the astrometric and photometric errors of the scanner. Digitizing was made with different spatial resolutions: 600, 900, 1200, 1500, 1800, 2100, 2400 and 2540 dpi. Calculations for the long-exposure stars that have twins with a short exposure are explained below.

The characteristics of the objects averaged over six scans were obtained for each scanning mode – rectangular coordinates *X, Y* and instrumental photometric magnitudes *m* and object diameters *f* (*FWHM*). Table.1 shows the average errors for eight resolution modes from 600 to 2540 dpi for stars brighter than $B \le 14^m$. Here, *k′* is the number of stars, σ_x, σ_y, σ_m, σ_f are the mean values of the root-mean-square errors for determining rectangular coordinates and photometric parameters. The errors are $\sigma_{xy}=0.017 \div 0.021$ px and $\sigma_m = 0.007^m$ for rectangular coordinates and instrumental magnitudes in 1200 dpi scan mode. Taking into account the scale factors (scale value is 1.45 for astrometry and for photometry, it is about 2 because of the contrast of the emulsion), practically, the errors will be 1.5-2 times larger. It allows for making the following conclusion. The Epson Expression 10000XL flatbed scanner and the developed software can be used digitizing and processing the plates and obtaining the characteristics of objects with internal accuracy better than 0.05″ and 0.015^m. For boundary faint objects ($B=16^m \div 17^m$), our studies yielded a result about two times worse.

Fig. 2 shows the relationship between instrumental magnitudes of long (m_1) and short (m_2) exposures for eight

Table 1. RMS errors of the rectangular coordinates and instrumental magnitudes

dpi	k'	σ_x	σ_y	σ_m	σ_f	*Scale* (″/px)
600	1833	0.020	0.014	0.008	0.039	2.893
900	2048	0.013	0.024	0.004	0.017	1.928
1200	2881	0.017	0.021	0.007	0.028	1.446
1500	2887	0.020	0.037	0.009	0.051	1.157
1800	2795	0.019	0.024	0.004	0.027	0.964
2100	2578	0.016	0.027	0.008	0.078	0.826
2400	2129	0.035	0.018	0.007	0.061	0.723
2540	1752	0.070	0.045	0.008	0.082	0.683

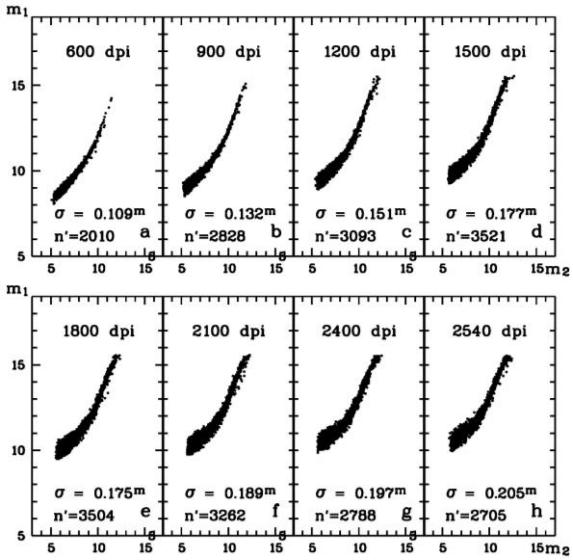

Figure 2: Relationships between instrumental magnitudes for different resolution of the scanner.

resolution modes of 600, 900, 1200, 1500, 1800, 2100, 2400 and 2540 dpi. *n'* is the number of studied stars for each scan mode. The relationship between the magnitudes is non-linear, and the accuracy of photometry σ increases via increasing of the scanning resolution.

4. Errors of reduction in the systems Tycho-2 and Johnson's B system

Table. 2 presents following parameters for the modes: *N* is the number of reference stars in Tycho-2; σ_α, σ_δ are errors of reduction of rectangular *X*, *Y* coordinates into the equatorial coordinates system - Tycho-2 [Andruk, 2015; Andruk, 2016] and σ_m is an error of the reduction of the instrumental magnitudes *m* into Johnson's *B* System [Andruk, 2017a; Relke, 2015].

5. Conclusion

The calculations and made analysis allow the authors to conclude as follows. Errors for each measurement are $\sigma_{\alpha\delta}$=0.07″ for the equatorial coordinates and σ_m=0.13^m for *B*-magnitudes in different resolution modes of the scanning. In practically, we have obtained the identity results for the processing of digitized images with 8-bit and 16-bit of color gradations. The scanner Epson Expression 10000XL is suitable for astrometric and photometric researches on the limit of accuracy of photographic plates. Studies show that the best option for digitizing is the 1200 dpi spatial resolution mode. High-resolution modes require more processing and digitizing time, and do not give a gain in accuracy for the obtained results. For example, the digitizing time with a resolution of 2400 dpi is 20 minutes, and with 1200 dpi, it is 8 minutes for astronegatives 30x30 cm size. Processing time also increases respectively to resolution.

Table 2. RMS errors of the equatorial coordinates and magnitudes

dpi	*N*	σ_α	σ_δ	σ_m	*Scale* (″/px)
600	1275	0.104	0.109	0.122	2.893
900	1282	0.071	0.083	0.103	1.928
1200	1487	0.067	0.070	0.139	1.446
1500	1472	0.066	0.070	0.124	1.157
1800	1120	0.055	0.055	0.120	0.964
2100	1144	0.057	0.052	0.128	0.826
2400	868	0.060	0.066	0.129	0.723
2540	854	0.053	0.055	0.137	0.683
		0.067	**0.070**	**0.125**	**1.328**

Until today, close to 2700 (the main part of them are astroplates of the FON project) of more than 15000 astronegatives had been digitized. Digitization was made with a resolution 1200 dpi, and 16-bit, gray color depth. A photographic catalog of equatorial coordinates and B-magnitudes of stars was created using the FON project astroplates [Yuldoshev, 2016a; Yuldoshev, 2016b; Yuldoshev, 2017a; Yuldoshev 2017b]. The catalog is available via this link http://vizier.u-strasbg.fr/viz-bin/VizieR?-source=I/346.

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