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

Q. Yuldoshev 1, V. Andruk 2, M. Muminov 3

1 Ulugh Beg Astronomical Institute of the Uzbekistan Academy of Sciences, 33 Astronomy Str., 100052 Tashkent, Uzbekistan, qudratillo@astrin.uz
2 Main Astronomical Observatory of National Academy of Sciences of Ukraine, 27 Akademika Zabolotnogo Str., 03143, Kyiv, Ukraine, andruk@mao.kiev.ua
3 Andijan State University, 129 University Str., 170100 Andijan, Uzbekistan, muminov1951@gmail.com

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 \( \sigma_\alpha=0.07" \) for the equatorial coordinates and \( \sigma_B=0.13" \) 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.

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 $I$, 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 $\Delta X$, $\Delta Y$, $\Delta m$, and $\Delta f$. 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=17.5$^m$ to 14$^m$. The limited 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$\leq$14$^m$. Here, $k$ is the number of stars, $\sigma_x$, $\sigma_y$, $\sigma_m$, $\sigma_f$ are the mean values of the root-mean-square errors for determining rectangular coordinates and photometric parameters. The errors are $\sigma_x=0.017+0.021$ 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$^m$ and 0.015$^m$. For boundary faint objects (B=16$^m$ to 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
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 \( \sigma \) 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; \( \sigma_\alpha, \sigma_\delta \) are errors of reduction of rectangular \( X, Y \) coordinates into the equatorial coordinates system - Tycho-2 [Andruk, 2015; Andruk, 2016] and \( \sigma_m \) 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 \( \sigma_\alpha=0.07'' \) for the equatorial coordinates and \( \sigma_\delta=0.13'' \) 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.

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

| dpi  | \( k' \) | \( \sigma_\alpha \) | \( \sigma_\delta \) | \( \sigma_m \) | Scale ("/px) |
|------|--------|----------------|----------------|-------------|-------------|
| 600  | 1833   | 0.026          | 0.016          | 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        |

Table 2. RMS errors of the equatorial coordinates and magnitudes

| dpi  | \( N \) | \( \sigma_\alpha \) | \( \sigma_\delta \) | \( \sigma_m \) | 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        |

\( \sigma_\alpha = 0.07'' \) for the equatorial coordinates and \( \sigma_\delta = 0.13'' \) for B-magnitudes in different resolution modes of the scanning.