Test of the scanner for expression of the astrometric and photometric parameters from the digitized plates

Accepted 7th September 2020

ABSTRACT

The present work has been performed to study in detail the Epson Expression 10000 XL scanner for photographic archive collection of the Ulugh Beg Astronomical Institute (UBAI) of the Uzbekistan Academy of Sciences. The specially developed software in the LINUX/MIDAS/ROMAFOT was used to process the plates. The test plate was digitized with grayscale 8 and 16 bits with different resolutions of the scanner. Astronomical and photometric parameters were obtained from the plate and an assessment of the accuracy of the developed method for determining rectangular coordinates and photometry, the repeatability of astrometric and photometric errors of the scanner for the digitized resolutions were processed.

Key words: Stellar catalogs, digitized plate processing, photometry, UBV system.

INTRODUCTION

The Ulugh Beg Astronomical Institute (UBAI) of the Uzbekistan Academy of Sciences is one of the oldest research institutes in Central Asia, which began its history more than 140 years ago. It was organized as Tashkent Astronomical Observatory (TAO) in 1873 and reorganized as UBAI in 1966. In 1895, the Tashkent Normal Astrograph (TNA) was installed in TAO and the astronomical observations were initiated. Using the photographic methods, UBAI obtained large number of photographic plates which had been stored in "glass archive" of UBAI. UBAI photographic archive consists of two parts. The first part of data was obtained by TNA during the period 1895-1986. The second part of the plates was taken from 1975 until the beginning of 2000 using Double Astrograph of Zeiss (DAZ), which was installed in 1975 at Kitab international latitudinal station (Kitab Observatory) of UBAI. The main characteristics of TNA and DAZ are presented in Table 1. More than 400 unique observations of Pleiades (exposure was up to 25 hours) and NGC 869, 884 (up to 30 hours) were made by V.V. Stratonov in 1896-1902. Over 700 photographic plates were obtained during 1919-1930 and many of them are bookmarks of the first eras of star clusters. About 800 images of different regions of the sky, including open clusters, were obtained in the period 1922-1931. The TNA collection also contains the astronomical plates of a number of major and minor planets, as well as valuable astronomical programs of A.N. Deutsch for areas of extragalactic nebulae.

Observations in Tashkent, were continued until 1986. The total number of photographic plates, obtained on the TNA, exceeds about 10000. The second part of observations was started in Kitab, after the installation of DAZ in 1975. This played a significant role in photographing the sky. The database of photographic data had been continuously replenished and today more than 15000 unique photographic plates are stored in the archive. In addition, the archive contains the "golden fund" of the DAZ- a photographic overview of the sky, which was observed under the project Photographic Sky Survey (in Russian, FON). These plates were exposed with fourfold overlap of all stars, galaxies and other celestial bodies from Declination -20° to +28°. In addition, the UBAI archive contains observational materials for the following projects as well: extragalactic nebulae and galaxies, open and globular star clusters, Solar system bodies (planets, comets and asteroids), star-forming regions, variable stars and...
areas of radio sources. At present, the archive has been cataloged according to international format. For digitization, the Epson Expression 10000 XL flatbed scanner, which is used in many observatories around the world, is used. In this paper, we present the methods and results of processing digitized images, scanned with different spatial resolutions from 600 to 2540 dpi.

### PROCESSING OF DIGITIZED ASTROPLATES

In FON project (Pakuliak, 2016; Andruk, 2017b), the process of extracting useful information from digitized photographic plates with an image of stellar field consists of the following main steps (Andruk, 2015b; Andruk, 2016):

1. Digitization of astronegatives using commercial flatbed scanner Epson Expression 10000 XL with the scanning modes—light transmitting mode / resolution is 1200 dpi / color depth is 16-bits gray. The sizes of the plates are 30x30 cm or 13000x13000 px, the scale is 1.45 °/px (Protsyuk, 2014a; Protsyuk, 2014b).
2. Conversion of all images from 16-bits TIF format to 8-bits FIT format using the GNU image manipulation program (GIMP) package.
3. Calculation of rectangular coordinates (X, Y), photometric instrumental magnitudes m and diameters of the object image f (FWHM) for all objects registered on the astronegative in the MIDAS/ROMAFOT environment.
4. Separation of registered objects into two exposures (Andruk, 2012).
5. Creation of a supplementary data file for identifying the rectangular and equatorial coordinates of reference stars.
6. Astrometric reduction for all objects in the equatorial coordinate system (α, δ) of the Tycho-2 catalog at the epoch of observation.
7. Estimation of photometric instrumental stellar magnitudes m in the system of photoelectric magnitudes Bpe (Andruk, 2017a).

The Epson Expression 10000 XL scanner is used to digitize the plates of the Kitab part of FON project in order to create a catalog of equatorial coordinates and B-magnitudes of stars (Yuldoshev, 2016a; Yuldoshev, 2016b; Yuldoshev, 2017a; Yuldoshev, 2017b) and making the tasks of other observational programs (Muminov, 2017; Shatokhina, 2018; Yizhakevych, 2018). Accuracy of astrometric and photometric characteristics of commercial scanners are studied in (Golovnya, 2010; Protsyuk, 2014a; Protsyuk, 2014b; Egilis, 2017; Mullo-Abdolov, 2017; Kashuba, 2018; Rahimi, 2018). To study the accuracy characteristics of the Epson Expression 10000 XL scanner, plate No. 399 was used, which was exposed on December 10, 1982 with the DAZ under the FON project (RA=5°36′, DEC=00°00′; emulsion - ORWO ZU21, exposures - 28 and 1 minute). In Figure 1, the fixed objects in the plate are mapped as produced by processing it using MIDAS/ROMAFOT environment.

### ESTIMATION OF PROCESSING ACCURACY OF DIGITIZED ASTRONEGATIVES IN THE MIDAS/ROMAFOT SOFTWARE ENVIRONMENT

The digitized images of the plates were obtained using the Epson Expression 10000 XL scanner in TIF format with 16-bits gray gradations. The digitized frames have to be converted to FIT format for processing in the MIDAS/ROMAFOT package, and the number of color gradations can be arbitrary. Depending on the number of color gradations (16-bits or 8-bits), the image sizes differ up to two times affecting the volume of needed disc space.

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<th>DAZ</th>
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<td>TAS040A</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(tube 1)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>&amp; TAS040B</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(tube 2)</td>
</tr>
<tr>
<td>Observatory Code</td>
<td>192</td>
<td>186</td>
</tr>
<tr>
<td>Longitude</td>
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<td>66°53′0″</td>
</tr>
<tr>
<td>Latitude</td>
<td>41°19′5″</td>
<td>39°08′0″</td>
</tr>
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</tr>
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<td>Aperture</td>
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</tr>
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<td>69 ″/mm</td>
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<tr>
<td>FOV</td>
<td>2°±2.5°</td>
<td>5.5°±6.0°</td>
</tr>
<tr>
<td>Plate size</td>
<td>16x16 cm</td>
<td>30x30 cm</td>
</tr>
</tbody>
</table>

---

Table 1: The main characteristics of TNA and DAZ.
on the stored disk. To estimate the possible loss of accuracy during the determinations of coordinates and photometry of stars when the images were converted from 16-bits (frame A) to 8-bits (frame B), a comparison of their processing was made. The objects were registered on the plate with two exposures: long and short exposures of 28 and 1 minute, respectively. After the processing of both frames for each object in the MIDAS/ROMAFOT software environment, we obtained their astrometric (rectangular coordinates \((X, Y)\)) and photometric characteristics (instrumental magnitudes \(m\), image diameters \(f\) (FWHM) and intensity values in the center of the image \(I_c\)) A total number \((n)\) of 3147 stars with long exposure were selected for studying. The results of comparison in the form of differences between the calculated values of the rectangular coordinates, the instrumental stellar magnitudes and the diameters of the objects are shown in Figure 2.

At the top of Figure 2, the trade of differences between the calculated values with a color depth of 8-bits and 16-bits for astrometric \((1a, 1b)\) and photometric \((1c, 1d)\) characteristics of stars relative to the rectangular coordinates \((X, Y)\), instrumental stellar magnitudes \(m\) and diameters of the objects \(f\) for the frames A and B are shown. The large and small values of \(m\) and \(f\) correspond to bright and faint stars, respectively. The mean square errors (RMS) of the difference between the first and second digitization methods are indicated. At the bottom of the figure \((2a\sim2d)\), these differences are shown as real (continuous lines) and theoretical (dashed lines) distribution functions versus the corresponding intervals \(k\). The length of the intervals \(\Delta x, \Delta y, \Delta m, \Delta f\) (0.4 values of standard deviations) and calculated values of \(X^2\) are shown in the right and left panels at the bottom of the figure. The data, given above, was obtained for the stars in the interval \(B=7^m\sim14^m\). For the long exposure the limiting magnitude is about \(B=17.5^m\). According to the additional studies, the quantities of the errors can be twice worst for extremely faint stars. As the RMS are less than 0.004 pixels and 0.002\(^m\) for the coordinates and magnitudes, respectively, it may be concluded that the digitization and processing of the plates could be made with 8-bits gray color depth.

**REPEATABILITY OF THE SCANNING RESULTS AND SCANNER ERRORS**

To evaluate the astrometric and photometric errors of the scanner, six consecutive scans of the plate were processed. Digitization was made with different spatial resolutions - 600, 900, 1200, 1500, 1800, 2100, 2400 and 2540 dpi. The calculations for the long exposure stars that have twins with a short exposure are explained as follows. For each resolution mode, the characteristics of the objects averaged.

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**Figure 1:** The map of the registered stars in plate No. 399 of the FON-Kitab project.
Figure 2: The differences between the calculated values of astrometric and photometric characteristics for the 8-bits and 16-bits images.

Figure 3: The trend of differences of six consecutive scans for the X coordinate and frequency distribution.

over six scans were obtained - rectangular coordinates \((X, Y)\), instrumental magnitudes \(m\) and object diameters \(f\). The left panel of the Figure 3 shows the differences of six consecutive scans relative to the averaged values of the
scan for the $X$ coordinates (1a-6a). After having corrected the systematic errors of the difference values for each scan, we will have the results that are shown in the same figure on the right panels (1b-6b). The number of studied objects (stars) $k$ and the RMS of the coordinate differences are also given in the right panel. The frequency distribution of these differences is shown at the bottom. The differences are given in the form of real (continuous lines) and theoretical (dashed lines) distribution functions at the corresponding intervals. The values of the interval length $\Delta X$ and $X^2$ (right and left, respectively) are indicated. Similarly, Figures 4 and 5 show the differences and their characteristics for the $Y$ coordinate and frequency distribution.
coordinates and instrumental magnitudes $m$. In Figures 3-5, the results are shown for the stars brighter than $B \leq 14$. 

As it was shown, for rectangular coordinates, the errors of one definition of difference are $\sigma_{xy}=0.014\pm0.028$ px, the errors of the definition of the instrumental stellar magnitudes are in the interval $\sigma_m=0.006m\pm0.009m$. By taking into account the scale of the scanning for the astrometry and the contrast of photographic emulsion...
being close to 1.5 and 2.0, respectively, the following conclusion can be drawn: the Epson Expression 10000 XL flatbed scanner with the special developed software allows the digitizing and processing of astronomical plates and obtain characteristics of objects, with an internal errors no worse than 0.07" and 0.02
. For the faint objects (B=16\textsuperscript{m}±17.5\textsuperscript{m}) these quantities are around twice bigger. This conclusion is for the scanning mode with 1200 dpi. The Figures 6-8 present similar outcomes for the 2400 dpi scanning mode. These results show that the errors for rectangular coordinates are $\sigma_x=0.016\pm0.056$ px, the errors in the determination of instrumental magnitudes do not exceed the values $\sigma_m=0.006\pm0.008$ m. For the 2400 dpi scanning mode, the scale factor is 0.723 /px for astrometry, that is, the accuracy of obtaining equatorial coordinates from processing the Epson Expression 10000 XL plates digitized on the scanner should be better than $\sigma<0.05"$.

As mentioned above, in this work six consecutive scans of plate No. 399 for each (600, 900, 1200, 1500, 1800, 2100, 2400 and 2540 dpi) scanning modes were made. For each scanning mode, object characteristics averaged over six scans were obtained - rectangular coordinates $(X, Y)$ and photometric instrumental magnitudes $m$ and $f$. In Table 2, the average error data for the scanning modes from 600 to 2540 dpi are given: $k'$ is the number of stars; $\sigma_x, \sigma_y, \sigma_m, \sigma_f$ are the mean values of the standard errors of the determination of rectangular coordinates and photometric quantities. The last column shows the scan scale in /px. Figure 9 shows the relationship between instrumental magnitudes of long ($m_1$) and short ($m_2$) exposures for the scanning modes. The number of studied stars $n$ in each scanning mode is indicated. The relationship between the $m_1$ and $m_2$ is nonlinear and the photometry errors $\sigma$ (their values are indicated on the panels) tend to increase as the scanning modes increase.

**ERRORS OF REDUCTION TO THE TYCHO-2 EQUATORIAL COORDINATE SYSTEM**

For the 5.5\textdegree x5.5\textdegree field, on the stage of the diagnosing of scanner’s systematic errors $\Delta\alpha$ and $\Delta\delta$, and on the stages of reducing the rectangular coordinates $(X, Y)$ of objects to the equatorial coordinates system $\alpha, \delta$ in the system of Tycho-2 catalog, the tangential coordinates $\xi, \eta$ have been calculated.
The photometric equation (photometric constants of stars from the catalog (Protsyuk, 2019) is the number of reference stars Tycho-2 catalog ($\sigma_\alpha$, $\sigma_\delta$) and the errors of stellar magnitudes ($\sigma_m$) for the scanning modes are presented in the Table 3.

**ERRORS OF REDUCTION OF STELLAR MAGNITUDES IN JOHNSON’S SYSTEM B**

The reduction of the measured stellar magnitudes of objects $m$ is the number of standard stars on the plates. $X_i$, $Y_i$, and $R_i$ are the coordinates and distances of the star images relative to the center of the plate. $m_i$ is the instrumental magnitude of objects, $f_i$ is the diameter of the stars, $a_2$, $a_3$, $a_4$, and $c_2$, $c_3$, $c_4$ are the coefficients, being responsible for the comma, $a_2$ and $c_2$ are the coefficients that take into account the influence of the telescope optics (calculated separately), $b_{lm}$ and $d_{lm}$ are the coefficients of the full six-degree polynomial describing the aberrations of the telescope optics burdened by the systematic errors of the scanner. Figure 10 presents the distribution of errors in the form of differences $\Delta_2$ in determining the equatorial coordinates $\alpha$ before (left) and after (right) corrections for systematic errors of the scanner for the scanning modes. The errors ($\sigma$) and the number of Tycho-2 reference stars ($k$) are indicated. Same processes were used for $\delta$ and results are shown in Figure 11. The process of the corrections for the scanner systematic errors along the ($X$, $Y$) coordinate is described in (Protsyuk, 2019). The results of the calculations: the number of reference stars Tycho-2(N), the errors of estimation of the rectangular coordinates ($X$, $Y$) of objects into the equatorial coordinate system of stars of the Tycho-2 catalog ($\sigma_\alpha$, $\sigma_\delta$) and the errors of stellar magnitudes ($\sigma_m$) for the scanning modes are presented in the Table 3.

**Errors of Reduction of Stellar Magnitudes in Johnson’s System B**

The reduction of the measured stellar magnitudes of objects $m$ is the number of standard stars on the plates. $X_i$, $Y_i$, and $R_i$ are the coordinates and distances of the star images relative to the center of the plate $m_i$ is the instrumental magnitude of objects, $f_i$ is the diameter of the stars, $a_2$, $a_3$, $a_4$, and $c_2$, $c_3$, $c_4$ are the coefficients, being responsible for the comma, $a_2$ and $c_2$ are the coefficients that take into account the influence of the telescope optics (calculated separately), $b_{lm}$ and $d_{lm}$ are the coefficients of the full six-degree polynomial describing the aberrations of the telescope optics burdened by the systematic errors of the scanner. Figure 10 presents the distribution of errors in the form of differences $\Delta_2$ in determining the equatorial coordinates $\alpha$ before (left) and after (right) corrections for systematic errors of the scanner for the scanning modes. The errors ($\sigma$) and the number of Tycho-2 reference stars ($k$) are indicated. Same processes were used for $\delta$ and results are shown in Figure 11. The process of the corrections for the scanner systematic errors along the ($X$, $Y$) coordinate is described in (Protsyuk, 2019). The results of the calculations: the number of reference stars Tycho-2(N), the errors of estimation of the rectangular coordinates ($X$, $Y$) of objects into the equatorial coordinate system of stars of the Tycho-2 catalog ($\sigma_\alpha$, $\sigma_\delta$) and the errors of stellar magnitudes ($\sigma_m$) for the scanning modes are presented in the Table 3.

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Figure 10: The distribution of the errors of determining the equatorial coordinates $\alpha$ before (left) and after (right) corrections for systematic errors of the scanner.

Figure 11: The distribution of the errors of determining the equatorial coordinates $\delta$ before (left) and after (right) corrections for systematic errors of the scanner.
of Equation (2) was selected to minimize the errors of photometric reduction in the system of photoelectric standards $B_{pn}$. The errors of reduction ($\sigma_m$) of instrumental magnitudes ($m$) to Johnson’s B system are given in the fifth column of the Table 3.

CONCLUSION

The present analysis and the calculations allow the authors to conclude as follow: for different scanning resolutions, the errors of one measurement are $\sigma_\alpha=0.07''$ for equatorial coordinates and $\sigma_m=0.13''$ for photometry. From the practices the results of processing of the digitized plates with 8 bits or 16 bits of color gradations are identified. According to the limits of accuracy for photographic plates, the Epson Expression 10000 XL scanner is suitable for performing astrometric and photometric work. Studies show that the most optimal option for digitizing is a mode with a spatial resolution of 1200 dpi. High resolution modes require a significant increase in processing time and do not give a gain in accuracy for the results. For example, scanning time with a resolution of 2400 dpi is about 20 minutes and in 1200 dpi mode, it is about 8 minutes for astronegatives with size of 30x30 cm. At present, more than 15000 astronegatives (the total number of digitized records is close to 2700 - the astronomical photographic plates of FON project) are stored in UBAI photographic archive. Digitization has been performed in a mode 1200 dpi/16-bits/gray. A photographic catalog of equatorial coordinates and B-magnitudes of stars was created under the FON project. The catalog of the project for Kitab part is available at this link http://vizier.u-strasbg.fr/viz-bin/VizieR?source=1/346.

REFERENCES


Table 3: The RMS errors of definitions of the equatorial coordinates and magnitudes for different resolution scanning modes.

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<th>$\sigma_\alpha$</th>
<th>$\sigma_m$</th>
<th>$\sigma_\delta$</th>
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The most optimal option for digitizing is a mode with 8 bits or 16 bits of color gradations. The present approach to the concept of the enhanced fon catalog compilation.


Shatkohina SV, Relke H, Yuldoshev Q, Andruk VM, Protsyuk Yu I, Muminov M (2018). Asteroids search results in digitized observations of the


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