Processing of Digital Plates 1.2m of Baldone Observatory Schmidt Telescope

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Abstract: The aim of this research is to evaluate accuracy of Plate Processing Method and to perform a detailed study of the Epson Expression 10000XL scanner, which was used to digitize plates from the database collection of the 1.2 m Schmidt Telescope installed in the Baldone Observatory. Special software developed in LINUX/MIDAS/ROMAFOT environment was used for processing the scans. Results of the digitized files with grey gradations of 8- and 16-bits were compared; an estimation of the accuracy of the developed method for rectangular coordinates determination and photometry was made. Errors in the instrumental system are $\pm 0.026$ pixels and $\pm 0.024$ m for coordinates and stellar magnitudes respectively. To evaluate the repeatability of the scanner’s astrometric and photometric errors, six consecutive scans of one plate were processed with a spatial separation of 1200 dpi. The following error estimations are obtained for stars brighter than $U < 13.5^m$: $\sigma_{xy} = \pm 0.021$ to 0.027 pixels and $\sigma_m = \pm 0.014^m$ to 0.016$^m$ for rectangular coordinates and instrumental stellar magnitudes respectively.

Keywords: astronegative, scanning, databases of glass archives, processing of digitized plates

1 Introduction

For 40 years, pictures of a large field of view has been obtained using the Schmidt Telescope at the Institute of Astronomy of the University of Latvia located near the small town of Baldone. The Baldone Observatory Schmidt Telescope (focal length = 240 cm, diam. = 120 cm, correction plate = 80 cm) is the twelfth largest telescope of this type in the world. The collection of astronomical photographs of Baldone Observatory (IAU code 069) contains more than 22000 direct images in the U, B, V, R, I bands and more than 2300 spectral images. The last one was obtained using a four-degree objective prism (spectral resolution 450 at the hydrogen gamma line). Each photo covers about 19 square degrees of the night sky. The purpose of the observations at the Baldone Observatory was to study the nonstationarity of stars at a late stage of evolution, especially carbon stars. Detailed description of photographic materials and filters used in observations and a list of observation objects are given in the works (Alksnis et al., 1998; Eglitis and Eglitis, 2016). Most of the observations were obtained by the astronomers A. Alksnis, I. Daube, L. Duncáns, I. Eglitis, I. Jurģitis, I. Platais, I. Pundure, A. Ruzhinski, P. Šimanskis and J.-I. Straume in the period from 1967 to 2005. Based on these observations, photometric characteristics of more than 300 carbon stars of the Milky Way and 70 novae in Andromeda galaxies were discovered and studied.

The amount of valuable information that can be extracted in astrophotography during a manual processing does not exceed 2 to 5 percent. The rest of useful information could be obtained after digitization and processing astrophotonegatives. Especially important in scans batch processing are brightness measurements of stars and galaxies in the U band (ultraviolet part of the spectrum). The amount of such measurements in the well-known astronomical database CDS (Centre de Données astronomiques de Strasbourg located in Strasbourg astronomical Data Center) now is very small. The Baldone archive could bring tangible benefits for studying long-period variations of stars’ brightness, because it contains regular observations for more than 30 years in several of areas of the North sky. The archive could also be useful for studying the motion of stars in the Milky Way and small bodies in the Solar System. As the first stage, it is planned to process more than 5000 records exposed in the U and V bands.
A specific software application was developed in LINUX/MIDAS/ROMAFOT environment to obtain rectangular coordinates and photometric characteristics of objects registered in digitized astronegaives. The software was created in 2004 by the Main Astronomical Observatory of the National Academy of Sciences of Ukraine (MAN) (Andruk et al., 2005a,b). At the same time, another application was developed in FORTRAN language and successfully used this software to determine the equatorial coordinates and photometric magnitudes of stars, galaxies, satellites of large planets, asteroids and other objects (Andruk and Pakuliak, 2007; Golovnya et al., 2010; Andruk et al., 2010, 2015c). Nowadays processing of large arrays of scanned plates has been successfully implemented, and catalogs of positions and stellar magnitudes of objects have been obtained for various observational programs: the FON program which processed 2260 plates of (MAN) and created the catalog of positions and B-values of 19.5 million stars and galaxies (Andruk et al., 2015a,b, 2016a,b); the first epoch of observations to obtain proper motions in the vicinity of the scattered clusters 290 plates were photographed in Nikolaev observatory and a catalog of positions and B-values of 2.7 million stars was obtained (Protsyuk et al., 2014d); Saturn’s satellites which processed 1385 positions from 250 astronanatives (Yizhakevych et al., 2015, 2016); other objects (Vavilova et al., 2014); observations of Uranus and Neptune where 1575 positions were obtained in different observatories (Protsyuk et al., 2015a, 2017); Pluto (59 positions) (Kazantseva et al., 2015) other (Protsyuk et al., 2015b; Muminov et al., 2017). In 2015 started scanning and processing of 2200 plates - Kitab observatory part of FON program (from 0 to –20 degrees) (Andruk et al., 2015b; Muminov et al., 2016) as well as over 1500 plates exposed in the U and V bands on 1.2 m Schmidt telescope (Alksnis et al., 1998; Eglite and Eglitis, 2016; Eglitis et al., 2016a,b, 2017). Stellar magnitudes of objects recorded in astronegaives are reduced to the Tycho2 catalog system or to the U, B, V system of photoelectric star measurements (Andruk et al., 1995; Kornilov et al., 1991; Mermilliod, 1991; Relke et al., 2015). Size of plates is 240x240 mm or 11000x11000 pixels (px) and the scale is 1.84"/px Conversion of files from 16-bit tiff format to 8-bit fits format using the GIMP package (Golovnya et al., 2010) Calculation of the rectangular coordinates (X, Y) and the photometric characteristics (instrumental values m and diameter of object image f (FWHM) in MIDAS/ROMAFOT environment for all objects registered in astroplate (Andruk et al., 2005a; Protsyuk et al., 2014a,b,c) Separation of registered objects (if necessary) by exposition (Andruk et al., 2012). Creation supplementary data file to identify rectangular and equatorial coordinates of reference stars Astrometric reduction for all objects in the equatorial coordinates a, δ in Tycho-2 catalog system for the epoch of plate exposure Photometric reduction of instrumental stellar magnitudes m to a system of photoelectric Upe, Bpe values (Andruk et al., 2010, 2017; Kornilov et al., 1991; Mermilliod, 1991; Relke et al., 2015).

Prior calculating the data of any registered objects in the ROMAFOT environment, photometric equalization of digitized frame with the star field image should be made in MIDAS. Figure 1 shows an example of a central photometric cross-sections in X, Y coordinates for plate No. 6978 exposed in the U-band at the 1.2 m Schmidt Telescope in Baldone, where sky region near the scattered cluster χ and h Perseus is exposed on the plate. The two upper panels of the figure shows the primary scan (a, b), the middle panels show the normalized cut for enveloping flat field of the plate (c, d), and the bottom panels show the resulting cuts after correcting the primary scan with the envelope of the plate flat field (e, f). For the cross section along the X coordinate in the center, glow of the gas-dust nebula is visible in the form of increased intensity I, for both parts of the cluster. After considering the flat field of plate, the effect of increased intensity in the center is absent (it could be a problem for correct photometry of stars). The process of fixing registered objects for the central part of the same plate is illustrated in Figure 2. The panels show consistently the photometric cut along the X coordinate of the central part of the plate after correcting flat field (a), aperture for objects (b), and the final view (c) before processing in the MIDAS/ROMAFOT. Diaphragms for objects (stars, galaxies, etc.) were created as described below. A photometric slice above a given level was taken (usually it is the sum of mean values of the flat field and three values of the photomulsion noise dispersion), then the pixels which are above a given level, are marked. Labeled objects (or already holes) should have the form of circles, ellipses and so on in projection to a plane. For a full photometric description of ob-

2 Processing of digitized astroplates of stellar fields

The process of extracting useful information from digitized plates with images of stellar fields consists of the following main stages:

Digitization of astronegaives using commercial scanners of Epson type, scanning mode - 1200 dpi (Protsyuk et al., 2014a,b).
Figure 1. The example of the central photometrical slices for coordinates X and Y for the plate Nr.6978. On the top two panels – for the original scan, on the middle two – the slice for the tangents of the flat plate field, on the bottom – the resulting slices after the correction of the original slices according to the tangent of the flat plate field.
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Figure 2. Photometrical slice for coordinate X for the central piece of the plate after making corrections for the flat field (a), diaphragm of the objects (b) and the final look (c).

Objects, dimensions of holes are increased by a radius of 2-3 pixels. We will have undistorted objects in the final image of the modified scan of the plate. Spaces between objects would be filled with the mean value of the flat field (sky background).

3 Estimation of processing accuracy of astronegatives in the MIDAS/ROMAFOT software environment

Digitized files of scanned plates were obtained using Epson Expression 10000XL scanner in tiff format with 16 bit grayscale. However for processing in MIDAS/ROMAFOT environment, digitized frames should be in fit format and color gradations could be arbitrary. Depending on the gradation colors (16 bits or 8 bits), the size of the file could differ up to 2 times, which affects the amount of disk space for storage. To evaluate possible loss of accuracy during the calculation of coordinates and stars photometry when files were converted from 16-bit (frame A) to 8-bit (frame B), a comparison of processing results was made. Frames A and B with spatial resolution were obtained for the plate number 15653, exposed in the U band of MEGA software (Andruk et al., 1995). Objects were recorded at the plate with two exposures: long and short (20 and 1 minute respectively). After processing both frames for each object in MIDAS/ROMAFOT environment, we have their astrometric (rectangular coordinates X, Y) and photometric (instrumental stellar magnitudes m, object image diameters f (FWHM) and intensity values in the image center I) characteristics. Figure 3 shows diagrams of functional dependences for these quantities for short (small dots) and long (large dots) expositions: f and m, I and m, I and f. Images of 351 bright objects were selected for the study.

Figure 4 shows the results of the above-mentioned comparison were calculated in the form of differences of rectangular coordinates, the instrumental stellar magnitudes and the diameter of the objects (stars) images. The upper part of Figure 4 shows the differences for frames A and B between the calculated values (by ROMAFOT soft-
ware) with a color depth of 8-bits and 16 bits for the astrometric characteristics (1a, 1b) and photometric characteristics (1c, 1d) of stars relatively to the rectangular coordinates of plate X, Y and instrumental values m and f. Higher and smaller values of m and f correspond to bright and weak stars respectively. The values for the standard deviation of the difference between the first and second digitization methods are indicated. In the lower part of the figure (2a, 2b, 2c, 2d), these differences are shown in the form of real (continuous lines) and theoretical (dashed lines) distribution functions in the corresponding intervals. On the right and left panels calculated values of intervals lengths $\Delta x$, $\Delta y$, $\Delta m$ and $\Delta f$ (that correspond to 0.4 values of standard deviations) and the sum of the values of $X^2$ are shown. The information above was obtained for stars in the interval $U = 6^{m} - 13.5^{m}$. For this plate, with an exposure of 20 minutes, the permeable value is $U < 17^{m}$. For extremely weak stars, the error values increase twofold according to the results of the research. Since the standard deviation of rectangular coordinates and stellar magnitudes differences are less than 0.005 pixels and 0.005$m$ respectively, it is possible and expediency to process digitized plates with 8-bit gradations of grey color.

4 Repeatability of scan results and scanner errors

Six consecutive scans of the plate No. 18103 (ORWO ZU21 + GG13, exp = 4 min) were processed to evaluate the scanner’s astrometric and photometric errors.

Scanning was performed with a spatial resolution 1200 dpi. Calculations for all objects recorded on the plate (more than 16 thousand) were made as follows. The object characteristics averaged over six scans were obtained - rectangular coordinates X, Y and instrumental stellar magnitudes m. The left part of Figure 5a shows the difference between six consecutive scans relatively to the average scan for the coordinates X (1a, 2a, 3a, 4a, 5a, 6a), while the right part (1b, 2b, 3b, 4b, 5b, 6b) shows the difference after correction for each scan as systematic errors. For all six scans the values for the standard deviation of one coordinate difference are indicated. The low part of Figure 5 shows the frequency distribution of these differences.

Differences are shown in the form of real (continuous lines) and theoretical (dashed lines) distribution functions in the corresponding intervals. The values of intervals length $\Delta x$ and values of $X^2$ (right and left, respectively) are specified. Similarly, Figure 5b and 5c show the differences and their characteristics for the Y coordinate and the instrumental stellar magnitudes m.

The results shown in Figure 5a-5c were obtained for stars brighter than $U \leq 14^{m}$. As we see in rectangular coordinates the error of one coordinate differences determination is $\sigma_{xy} = \pm 0.021 - 0.027$ pixels, the error of determining the instrumental stellar magnitudes do not exceed $\sigma_m = \pm 0.014^m - 0.016^m$.

Considering the scale factor (which is a value close to two units due to the scale and the technical characteristics of scanning for astrometry and the contrast of photoemulsion) errors for the system of equatorial coordinates and U-values would be twice as much in practice. We can make the following conclusion.

The Epson Expression 10000XL flatbed scanner together with the developed software allows digitizing and processing the plates, to get the characteristics of objects (high, moderate and weak brightness) with the internal
Figure 4. On the top part on the picture the difference between calculated values of gray 8-bit and 16-bit are shown for astrometrical (1a, 1b) and photometrical (1c, 1d) star characteristics relatively to the rectangular coordinates of the plate X, Y and instrumental values m, f, (FWHM) relatively. The values of the single difference between two ways of the plates digitizing is provided. On the bottom of the picture 2a, 2b, 2d, 2c the differences are given in the form of real (solid lines) and theoretical (dash lines) distribution functions for the respective intervals. The values of the interval lengths are given ($\Delta x$, $\Delta y$, $\Delta m$, $\Delta f$) and the value $X^2$ is calculated (on the right and on the left respectively). The given data is received for the stars in the interval $U = 6^m \div 13.5^m$. 
Figure 5a. The differences for the six consecutive scans relatively to the average scan for coordinate X. On the bottom the frequency distribution of the differences. The values are given in the form of real (solid lines) and theoretical (dash lines) distribution functions for the respective intervals. The value of interval length Δx and the value $\chi^2$ (on the right and the left respectively) are given.
Figure 5b. The differences for the six consecutive scans relatively to the average scan for coordinate Y. On the bottom the frequency distribution of the differences. The values are given in the form of real (solid lines) and theoretical (dash lines) distribution functions for the respective intervals. The value of interval length $\Delta y$ and the value $\chi^2$ (on the right and the left respectively) are given.
Figure 5c. The differences for the six consecutive scans relatively to the average scan for the instrumental value $m$. On the bottom the frequency distribution of the differences. The values are given in the form of real (solid lines) and theoretical (dash lines) distribution functions for the respective intervals. The value of interval length $\Delta m$ and the value $X^2$ (on the right and the left respectively) are given.
error not worse than ±0.05 seconds of the arc and ±0.03 magnitude. For marginally weak objects \((U = 16^m - 17^m)\) our studies gave a result about twice as bad.

This conclusion concerns the scanning modes of 1200 dpi for astronegatives of 240x240 mm size. Similar studies of these type scanners were made in observatories in MAN, Nikolaev, and Kitab observatories. The results are presented in the paper (Protsyuk et al., 2014a).

5 Conclusions

According to the results of this work, the main result concerning the technical characteristics of digitized plates processing by Epson Expression 10000XL scanner was as follows. Within the limits of accuracy for photographic plates Epson Expression 10000XL scanner is suitable for performing astrometric and photometric works for terrestrial astronomy.

Errors of one measurement are ±0.05 seconds of the arc for equatorial coordinates and ±0.03 of the stellar mag-
plitude for U-values. An important practical result is the identity of digitized scans processing with 8 or 16 bits color gradation.

The results are based on the software developed in the MIDAS/ROMAFOT environment (Andruk et al., 2015a,b,c, 2016a,b; Eglitis et al., 2016a,b; Kazantzseva et al., 2015; Yizhakevych et al., 2016; Pakuliak et al., 2016). Figure 6 shows a map of the star-sky section of the double cluster χ and h of Perseus based on the processing of plate No. 6978.

References