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

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Данная работа выполнена с целью оценки точности метода обработки пластинок и детального исследования сканера Epson Expression 10000XL, с помощью которого оцифровываются пластинки ФОН (фотографический обзор неба) из коллекции стеклотеки Астрономического института Академии наук Узбекистана. Для обработки астропластинок используется программное обеспечение, созданное в программной среде LINUX/MIDAS/ROMAFOT. Из сравнения результатов обработки оцифрованных файлов с градациями серого 8 и 16 бит сделана оценка точности разработанного метода определения прямоугольных координат и фотометрии. Для оценки повторяемости астрометрических и фотометрических ошибок сканера были обработаны по шесть последовательных сканов одной пластинки с пространственным разрешением 600, 900, 1200, 1500, 1800, 2100, 2400 и 2540 dpi.

Ключевые слова: звездные каталоги, обработка оцифрованных пластинок, фотометрия, фотометрическая система.

This paper performs to research in detail the Epson Expression 10000XL scanner for photographic astroplate archive of the Ulugh Beg Astronomical Institute (UBAI) of the Uzbekistan Academy of Sciences. For processing the astroplates, it is used special developed software in the LINUX/MIDAS/ROMAFOT. The test plate was digitized with grayscale 8 and 16 bits with various scanner resolutions. Astronomical and photometric parameters were carried out from the plate and an evaluation of the developed method accuracy for determining rectangular coordinates and photometry. The repeatability of astrometric and photometric errors of the scanner for the digitized resolutions, 6 successive scans of every plate with a spatial resolution 600, 900, 1200, 1500, 1800, 2100, 2400 and 2540 dpi were processed.

Keywords: stellar catalogs, digitized plate processing, photometry, photometric system.

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I. Introduction

The Ulugh Beg Astronomical Institute (UBAI) of the Uzbekistan Academy of Sciences has been operating for almost a century and a half. It is one of the oldest research institutes in Central Asia. It was first established as the Tashkent Astronomical Observatory (TAO) in 1873 and reorganized as the UBAI in 1966.

In 1895, the first astronomical observations were commenced with the installation of the Tashkent Normal Astrograph (TNA) in TAO. UBAI received a great number of photographic plates using the photographic plates which are reserved in UBAI plate archive.

The UBAI photographic plate archive contains two observation periods. The first period was 1895-1986, and observations during this period were carried out by TNA. The second observation period was from 1975 to the early 2000-s. In this period, it was used the Dual Astrograph of Zeiss (DAZ) installed at the UBAI International Latitude Station (Kitab Observatory) in 1975. During the whole period the database of photographic data had been continually refilled and today about 20000 unique glass astroplates are reserved in the UBAI archive. Furthermore, the archive comprises the "golden fund" of the DAZ – a photographic overview of the sky and these observations were carried out within the framework of the project FON (Photographic Sky Survey, Russian abbreviation is FON).

Nowadays, we cataloged the archive plates in accordance with international format. Usually, it is used the Epson Expression 10000XL flatbed scanner for digitization of observation data at many observatories around the world. This work present σαδ=0.07″ for equatorial coordinates, the methods and processing results of digitized images, scanned with various spatial resolutions from 600 to 2540 dpi.

II. Processing of digitized astroplates

In FON project [1, 2] the process of taking out profitable data from digitized photographic plates contains basic steps in below [3, 4]:

1. Digitization of astroplates using commercial flatbed scanner Epson Expression 10000XL with the light transmitting mode/with various resolutions/color depth is 16-bits gray. Plate sizes are 30×30 cm or 13000×13000 pixels, the scale is 1.45″/px [5, 6].

2. Transformation of all images from 16-bits TIF (Tagged Image File) format to 8-bits FIT (Filtering Integration Technology) format (General Image Manipulation Program-GIMP) package using the GNU (Gnu Not Unix) image manipulation program.

3. Computation of rectangular coordinates (X, Y), diameters of the object image *f* (FWHM - Full spectrum Width at Half Maximum) and photometric instrumental magnitudes *m* for all objects determined on the astroplates.

4. Disconnection of listed objects into two expositions [7].

5. Formation of an additional data file for defining the rectangular and equatorial coordinates of reference stars.

6. Astrometric contraction for all celestial objects in the equatorial coordinate system (α, δ) of the Tycho-2 catalog at the observation epoch.

7. Evaluation of photometric instrumental stellar magnitudes *m* in the system of photoelectric magnitudes B_{pe} [8].

It is used the Epson Expression 10000XL scanner to digitize the plates of the Kitab part of FON project for generating a catalog of *B*-magnitudes and equatorial coordinates of stars [9-12] and performing the missions of some observational programs [13-15]. Accuracy of astrometric and photometric characteristics of commercial scanners are explored in the reference [16, 5, 6, 17-20].

Plate No.399 was used for researching the Epson Expression 10000XL scanner accuracy characteristics, which was revealed on December 10.1982 with the DAZ under the FON project.

Figure 1 shows the fixed objects in the plate are mapped as produced by processing it using MIDAS/ROMAFOT environment.

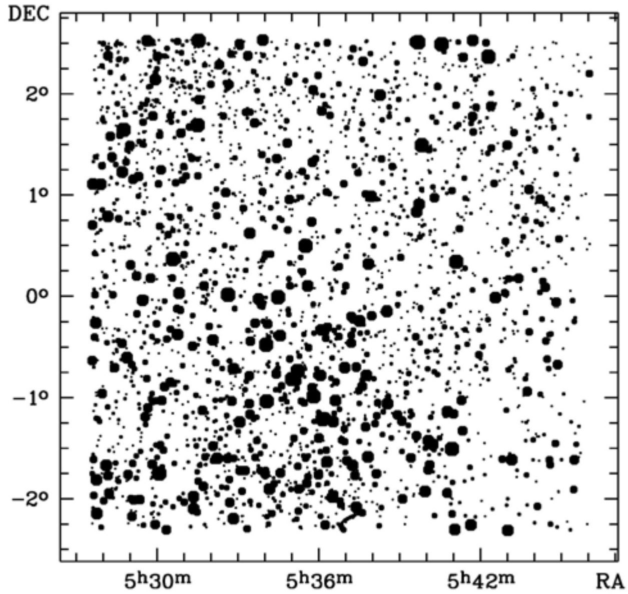

Figure 1. The map of the registered stars in the plate No.399 of the FON project.

III. Evaluation of processing accuracy of digitized astroplates

The digitized images of the plates were obtained in TIF format with 16-bits gray gradations. The digitized frames are transformed to FIT format for processing in the MIDAS/ROMAFOT package, and the color gradations number could be arbitrary. Dependence with the color gradation numbers of 16-bits or 8-bits, the image sizes change to two times affecting the volume of the disc $\sigma_{\alpha\delta}$=0.07″ for equatorial coordinates on the reserved disk. To evaluate the possible losing of accuracy during the defining photometry and coordinates of stars when the images were changed from 16-bits to 8-bits, a comparison of their processing was made. Registered objects on the plate with two exposures are short and long exposures: 1 minute and 28 minutes.

In the MIDAS/ROMAFOT programming environment, both frames are processed for each object, then, we derived their photometric and astrometric characteristics. As well as, we chose 3147 stars with long exposure for investigating.

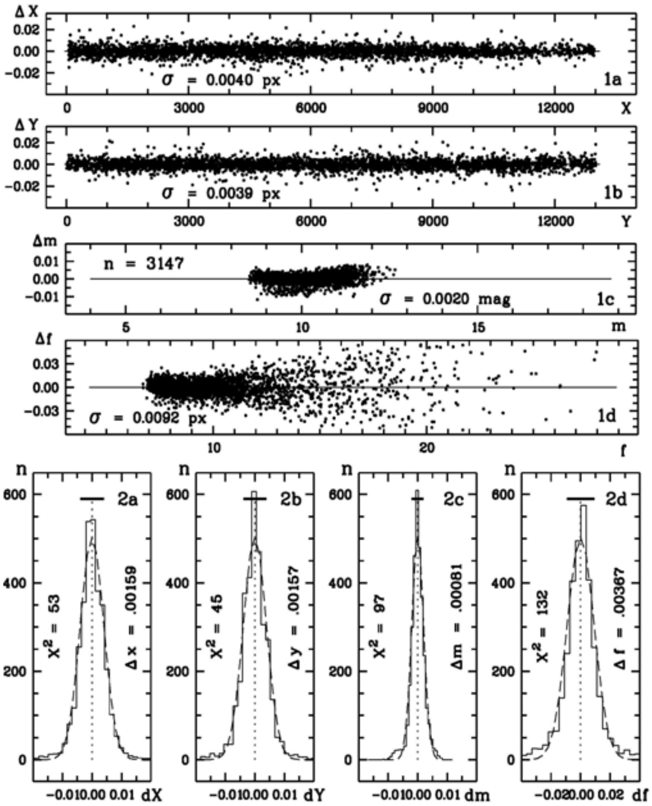

Figure 2. The differences between the calculated values of photometric and astrometric characteristics for the 16-bits and 8-bits images.

Figure 2 shows the outcomes of comparison in the form of distinctions among the calculated values of the diameters of the objects. The different values with 16-bits and 8-bits for photometric (1c, 1d) and astrometric (1a, 1b) characteristics of stars connected to the rectangular coordinates (X, Y), instrumental stellar magnitudes m and diameters of the celestial objects f for the frames are given in Fig. 2.

The different values of m and f are consistent with faint and bright stars. The digitization methods differ from each other and the mean errors (RMS) of these differences are given 2a-2d in Fig.2, these distinctions are given as theoretical (dashed lines) and practical (continual lines) distribution functions over the corresponding intervals k. This figure also shows the lengths of the intervals Δx, Δy, Δm, Δf and computed values of X^2.

These data were obtained for stars in the interval $B=7^m–14^m$. A limit of the magnitude for a long exposure is approximately $B=17.5^m$. In accordance with detailed studies, the quantity of uncertainties can be two times larger for too faint stars. Since the RMS values are less than 0.002^m and 0.004 pixels for magnitudes and coordinates, it could be inferred that processing and digitizing astroplates can be done with 8-bit gray depth.

IV. Scanning results and scanner errors repeatability

Six seriated scans of the plate were processed to evaluate the astrometric and photometric uncertainties of the scanner. Digitization was carried out with various spatial resolutions: 600, 900, 1200, 1500, 1800, 2100, 2400 and 2540 dpi.

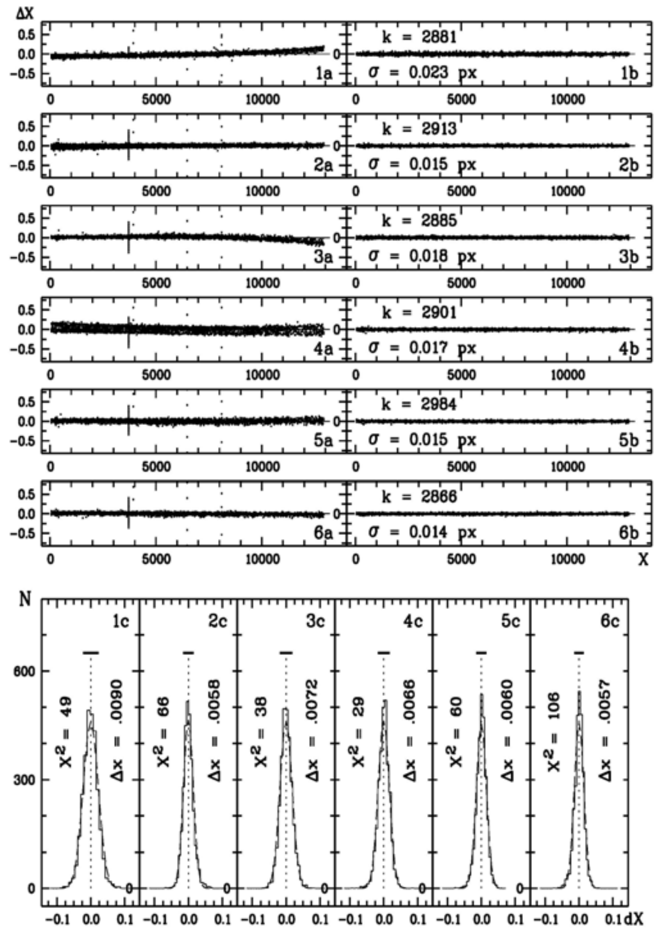

Figure 3. The difference trend of 6 consequent scans for X coordinate and frequency distribution.

The divergences of six seriated scans respective to the average scan values for the X coordinates (1a–6a) are shown in Fig. 3. The results are given in the same figure on the right panels (1b–6b) after correcting systematic errors of the different values for each scan. In the right panel, the RMS of differences of coordinates and the number of studied stars (*k*) are given. Figure 3 also gives the frequency distribution of these distinctions.

Differences are given as theoretical (dashed lines) and practical (solid lines) distribution functions for the suitable intervals. The interval length values of X^2 and Δx is shown. In a similar way, Fig. 4 and 5 represent the divergences and characteristics for the magnitudes $m_{\sigma\alpha\delta}$=0.07″ for equatorial coordinates and the *Y* coordinates. Figures 3–5 present the results for brighter stars than $B \leq 14^m$. The defining errors of the magnitude interval is $\sigma_m = 0.006^m – 0.009^m$, for rectangular coordinates of one defining errors of the divergence are σ_{xy}=0.014–0.028 px.

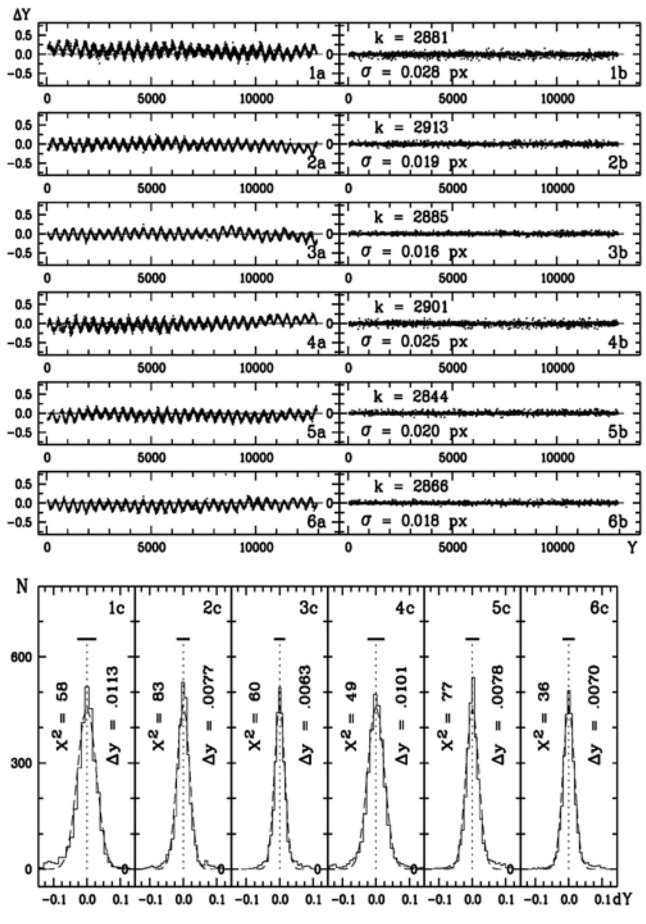

Figure 4. The difference trend of 6 consequent scans for the *Y* coordinate and frequency distribution

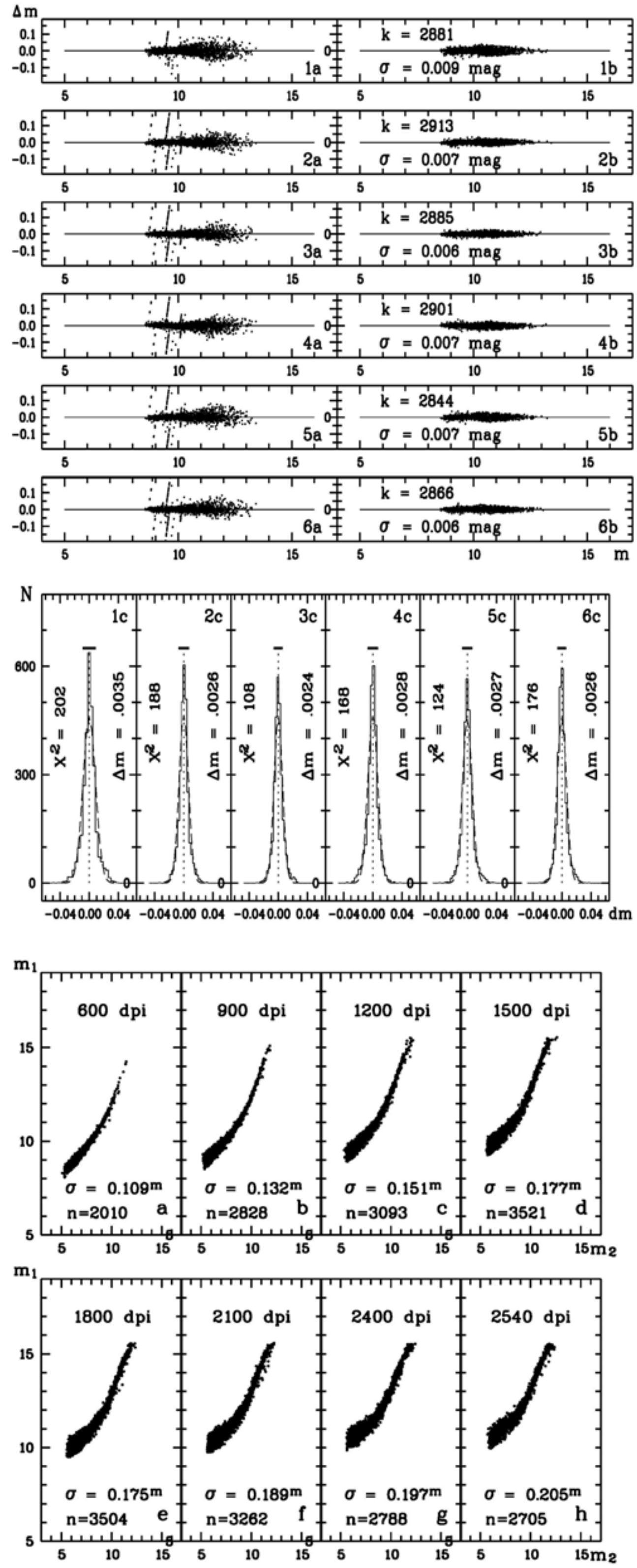

Figure 5. The trend of differences for the instrumental magnitudes *m* and the frequency distributions.

We can give the following conclusion. The Epson Expression 10000XL flatbed scanner with especially prosperous software permits us to digitize and process astronomical plates and getting the characteristics of objects with an error not worse than 0.07″ and 0.02^m developed for faint objects (B=16^m, 17.5^m) these values are about twice as large. Such an output for the scanning mode: 1200 dpi.

Figures 6–8 represent almost the same outcomes with the 2400 dpi mode. These results show that it was obtained errors for rectangular coordinates σ_{xy}=0.016–0.056 px, then the errors in determining instrumental magnitudes do not transcend the values σ_m=0.006^m–0.008^m. For the 2400 dpi mode, the scale factor is 0.723″/px for astrometry, getting equatorial coordinates when processing the plates digitized on the scanner must be better than σ<0.05″.

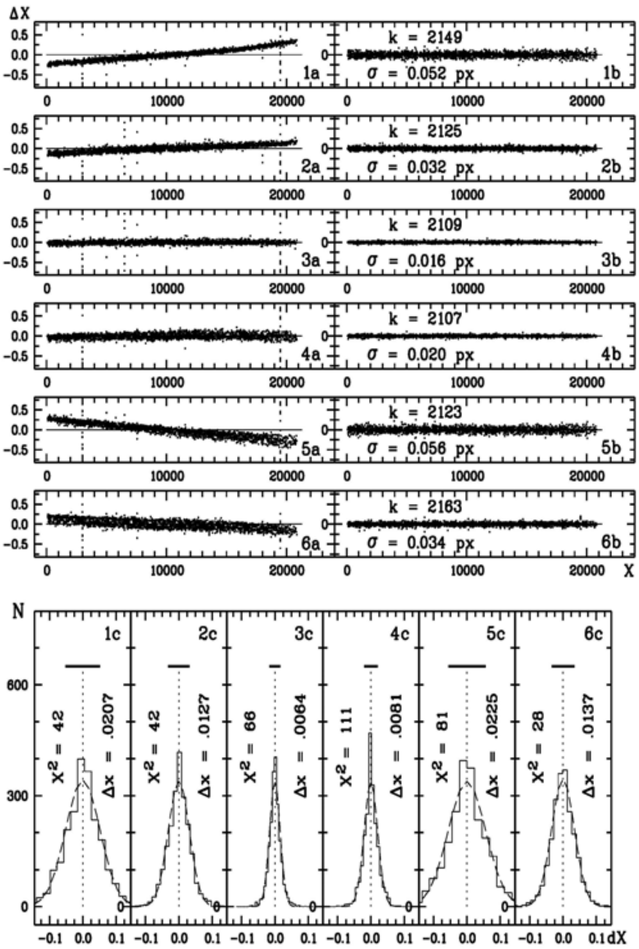

Figure 6. The trend of differences of 6 consequent scans for the X coordinate and frequency distribution for the 2400 dpi scanning resolution.

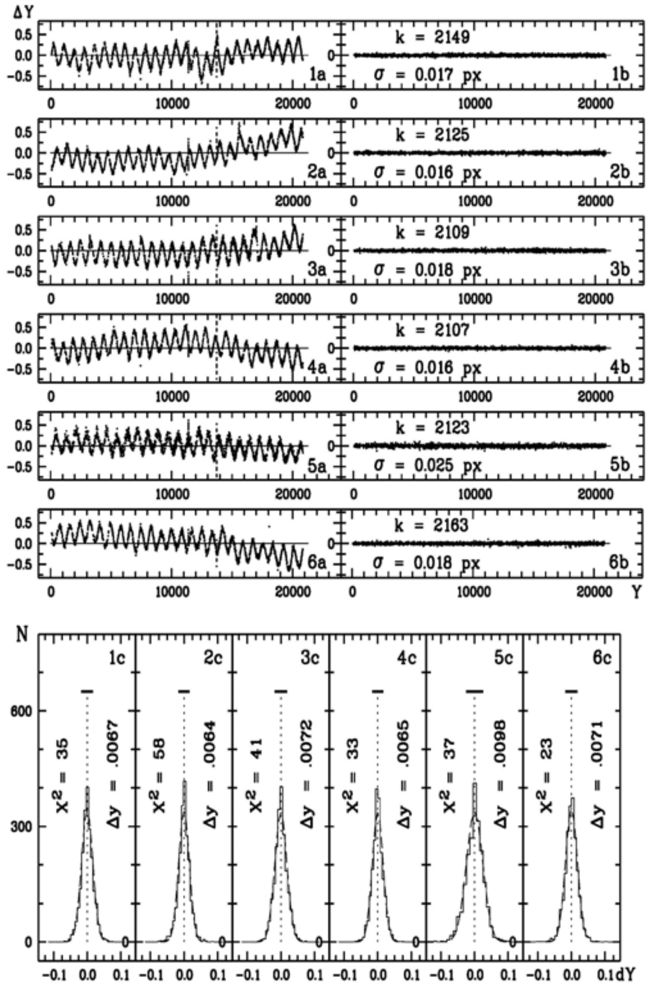

Figure 7. The trend of differences of 6 consequent scans for the Y coordinate and frequency distribution for the 2400 dpi mode. $\sigma_{\alpha\delta}$=0.07″ for equatorial coordinates.

As stated above, in this paper six consequent scans of plate No.399 were performed for each mode (600, 900, 1200, 1500, 1800, 2100, 2400, and 2540 dpi). For every mode, the object characteristics were received.

Table 1 gives the average error data for scanner modes from 600 to 2540 dpi: k' – star numbers; σ_x, σ_y, σ_m and σ_f – the mean average values of the standard errors for determining photometric quantities and rectangular coordinates. The last column represents the scan scale in ″/px.

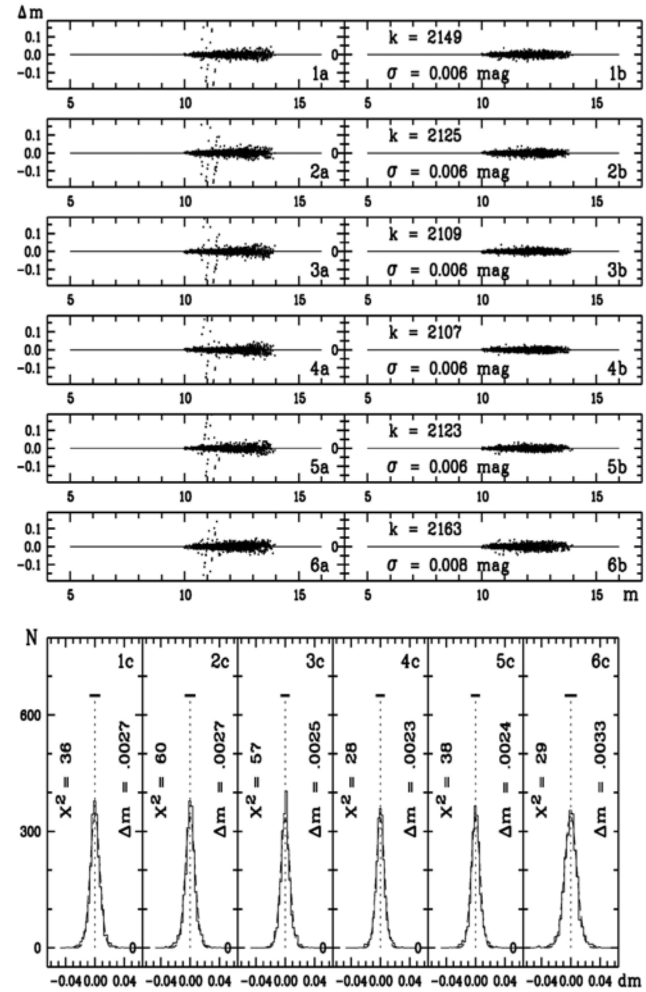

Figure 8. The trend of differences for the instrumental magnitudes *m* and the frequency distributions of the differences for the 2400 dpi scanning mode.

Table 1. The RMS errors of instrumental stellar magnitudes and definitions of the rectangular coordinates for various resolution scanning modes.

dpi	k'	σ_x	σ_y	σ_m	σ_f	scale
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 9 represents the connection between the values of short (m_2) and long (m_1) exposures for scanner modes. We reported the number of researched stars *n* in each scanner mode. The connection between m_1 and m_2 is non-linear, and the photometry errors σ (their values are given on the panels) increase with increasing scanner modes.

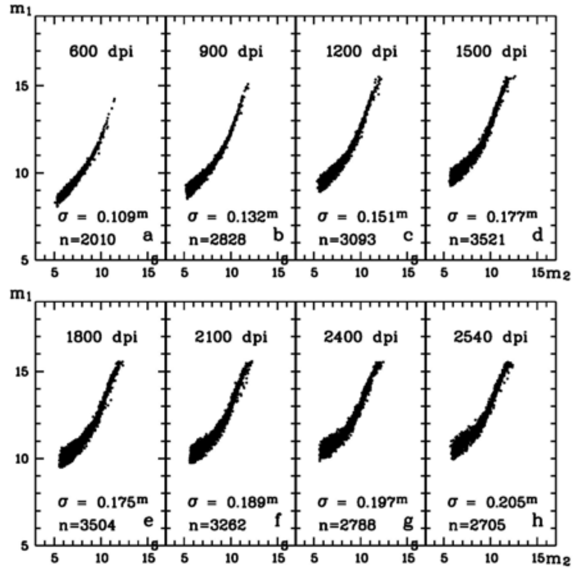

Figure 9. Connection between instrumental magnitudes for various scan modes.

V. Shortening errors in the Tycho-2 equatorial coordinate system

In the field of 5.5°×5.5° at the estimating systematic scanner errors Δα and Δδ with the reducing of the rectangular coordinates *(X, Y)* of objects to the equatorial coordinate system α, δ in the Tycho-2 catalog, tangential coordinates ξ, η have been calculated by the least squares method in accordance with expression (1):

$$\begin{aligned} \xi_i &= a_1 + a_2 X_i f_i + a_3 Y_i f_i + a_4 R_i m_i + a_5 f_i + \sum b_{lm} X_i^l Y_i^m, \\ \eta_i &= c_1 + c_2 X_i f_i + c_3 Y_i f_i + c_4 R_i m_i + c_5 f_i + \sum d_{lm} X_i^l Y_i^m, \quad (1) \\ & (l = 0-6, m = 0-6, l+m = n, n = 1-6), \end{aligned}$$

where $i = 1, 2, \ldots, n$ is the number of reference stars from the Tycho-2 catalog system on the plate; X_i, Y_i – the coordinates and R_i – distances of the star images corresponding to the plate center; m_i – the instrumental value of objects and f_i – stars diameter; a_2, a_3, a_4 and c_2, c_3, c_4 are the coefficients responsible for the comma; a_5 and c_5 are coefficients that take into account the effect of the brightness equation; b_{lm} and d_{lm} are six-degree full polynomial coefficients that describes the telescope optics aberrations, loaded by the systematic errors of the scanner.

Figure 10 represents errors distribution in the form of divergences Δα in defining the equatorial coordinates α before (left) and after (right) corrections for systematic errors of the scanner for various modes.

In addition, in this figure we can see the errors (σ) and Tycho-2 reference stars number (*k*). We used similar processes for δ and the result is presented in Fig. 11. Processes for improving systematic errors of the scanner in coordinates (*X*, *Y*) are depicted in [21].

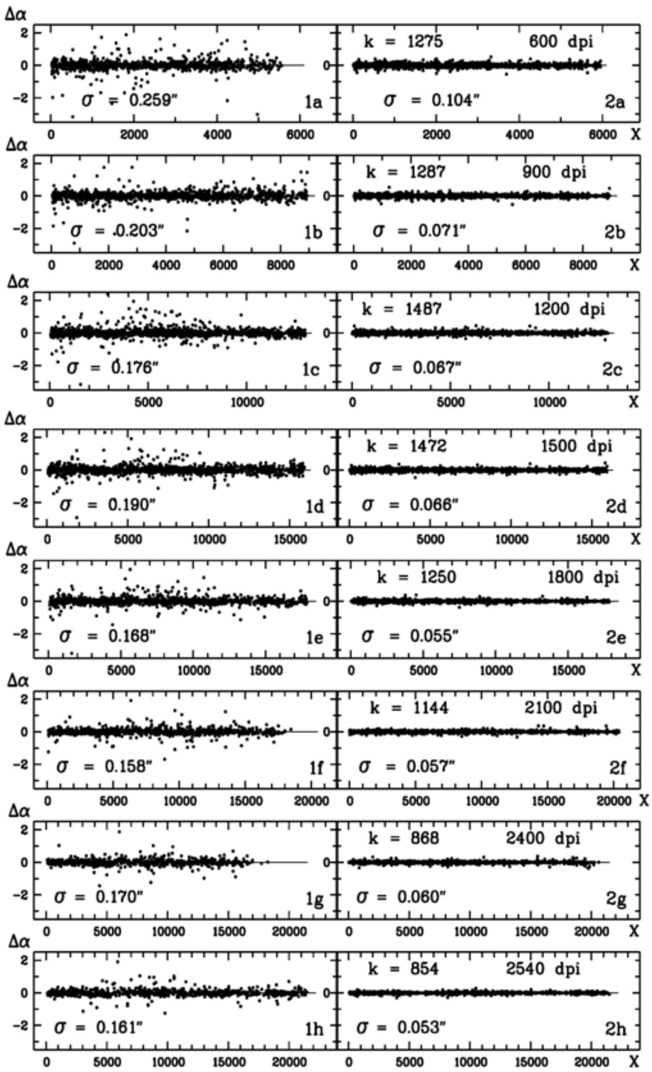

Figure 10. The distribution of the errors of determining the equatorial coordinates *α* before (left) and after (right) amendments for systematic errors of the scanner.

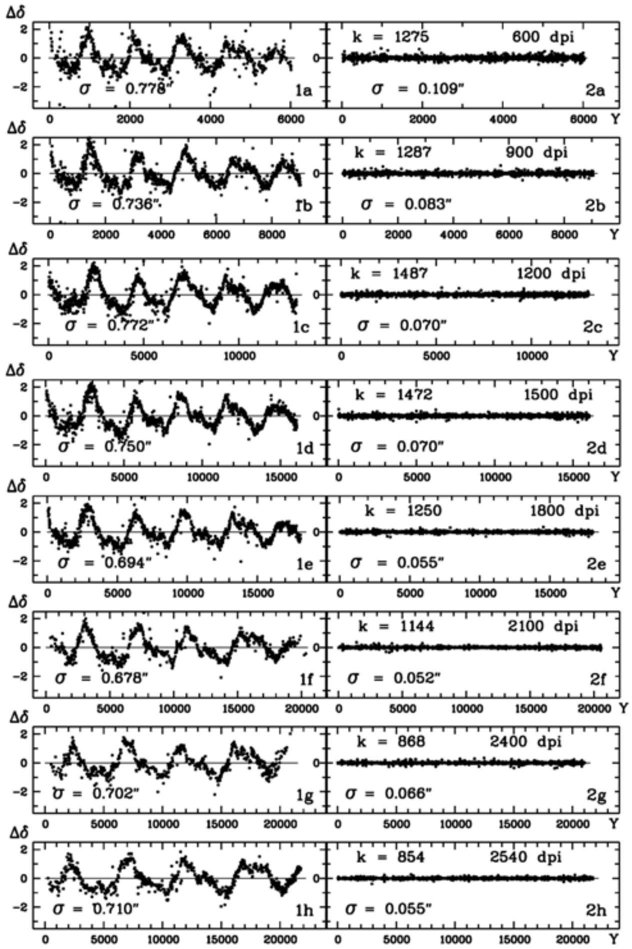

Figure 11. The distribution of the determining the equatorial coordinates δ errors before (left) and after (right) amendments for scanner systematic errors.

The results: The number of Tycho-2 reference stars' (*N*), magnitude errors (σ_m) for scan modes and errors in evaluating the rectangular coordinates (*X, Y*) of objects in the equatorial coordinate system of Tycho-2 catalog stars (σ_α, σ_δ) are given in following Table 2.

Table 2. The RMS errors of the equatorial coordinates' definitions and magnitudes for different resolution scanning modes.

dpi	*N*	σ_α	σ_δ	σ_m	scale
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

VI. Errors of reduction of stellar magnitudes in Johnson's System B.

Processing of the measured stellar magnitudes m of celestial objects in Johnson's B_{ph} photographic system was obtained from the characteristic curve of astroplates. The characteristic curve is constructed using photoelectric measurements of stars from the [22] catalog and B_j values from the Tycho-2 catalog. In the paper [23], the constructing process a characteristic curve for stars with two exposures is depicted.

The characteristic curves were approximated by solving the equations by the least squares' method using the expression (2):

$$B_i = e_1 + e_2 X_i + e_3 Y_i + e_4 R_i + e_5 R_i^2 + e_6 R_i^4 + \sum f_n m_i^n \quad (n = 1 \div 5) \tag{2}$$

where i=1,2, …, n is the photoelectric determinations standard stars number on the plates. R_i – distances, X_i, Y_i – coordinates of the star images relative to the center of the plate. m_i – the magnitudes of the stars. The coefficient f_n is consistent with the functional description of the curve. e_2, e_3, e_4, e_5 – the coefficients of the photometric equation of the field.

The equation (2) was chosen to minimize photometric processing errors in the system of B_{pe}. photoelectric standards. Reduction errors (σ_m) of instrumental quantities (m) to the Johnson system B are presented in the fifth column of Tab. 2.

VII. Conclusion

Based on the analysis and calculations, the authors conclude that a single measurement errors for different scanning resolutions are σ_m=0.13 m for photometry and $\sigma_{\alpha\delta}$=0.07″ for equatorial coordinates. The results of processing digitalized plates with 8-bit or 16-bit color gradations are determined. The Epson Expression 10000XL scanner is acceptable for performing astrometric and photometric work within the accuracy limits for photographic plates. Researches show that the most optimal option for digitizing is a mode with a spatial 1200 dpi resolution. High resolution modes require a considerable magnification in processing time and do not improve the accuracy for the results. For example, for astronegatives with size of 30×30 cm, scanning time with a resolution of 2400 dpi is about 20 min and with a resolution of 1200 dpi, it is about 8 min.

Currently, the UBAI photo archive stores more than 15000 astronegatives (the total number of digitized records is about 2700 photographic astroplates of the FON project). Digitization was carried out in 1200 dpi/16-bit/gray mode. Within the framework of the FON project, a photographic catalog of B-magnitudes of stars and equatorial coordinates has been created. This catalogue is available at the link http://vizier.u-strasbg.fr/viz-bin/VizieR?-source=I/346.

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Рақамлаштирилган фотопластинкалардан астрометрик ва фотометрик параметрларни олиш учун сканер синови

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Мазкур ишда ЎзР ФА Астрономия институти фотографик архивидаги ФОН (Фотографический Обзор Неба) лойиҳаси асосида олинган фотопластинкаларни рақамлаштириш асосида Epson Expression 10000XL сканерини батафсил тадқиқ қилиш ва тасвирларни қайта ишлаш (таҳлил қилиш) услублари аниқлигини баҳолаш ишлари амалга оширилди. Астротасвирлар (рақамлаштирилган фотопластинкалар) LINUX/MIDAS/ROMAFOT дастурлар пакетида яратилган дастурий таъминотдан фойдаланган ҳолда қайта ишланди. 8 ва 16 битли кулранг тасвирларни қайта ишлаш натижалари таққосланди ҳамда тўғри бурчакли координаталар ва инструментал юлдуз катталикларини аниқлаш учун ишлаб чиқилган услубнинг тўғрилиги баҳоланди. Сканернинг астрометрик ва фотометрик хатолари такрорийлигини баҳолаш учун битта фотопластинканинг 600, 900, 1200, 1500, 1800, 2100, 2400 ва 2540 dpi режимларда кетма-кет олтитадан сканерлаш ва қайта ишлаш текширувлари ўтказилди.

Калит сўзлар: юлдуз каталоглар, фотопластинкаларни рақамлаштириш, фотометрия, фотометрик тартиб.