Mobile Device for Digitizing of photographic plates: the first results

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Abstract — The first results of astrometrical reduction for 40 Saturn and Pluto's plates are presented. Digitization of plates had been made using Mobile Device to Digitize (MDD) based on 21.1 megapixel full-frame Canon EOS 5D Mark II digital camera. The speed of digitization is 60-70 plates per hour. Random error of measurements for the same plate is about 0.7-0.8 μm. The matters of calibration are discussed.

Introduction

The glass plate archive of Pulkovo Observatory has more than 50 000 astronegatives, 5000 of them have never been measured. Photographic plates require urgent digitization and measurements, because the quality of photo emulsion becomes worse with the course of time. This method of digitization and astrometric reduction of photographic plates using a digital camera is developed due to the problem of plate archive transportation to the high-tech measuring machines. The plate digitization using scanner were performed earlier, the measurement accuracy of 1 micron was reached only in a limited field of 20 x 20 mm. Large fields were distorted with irregular errors.

The series of parallactic observations of the double star ADS 8002 was chosen to test the method. The series consists of 55 plates obtained at the 26-inch refractor. The number of exposures on the one plate is from 5 to 20. We used five reference stars in the field of 75x90 mm. Calibration was performed by measuring template, pre-measured on the digitizer of Royal Observatory of Belgium (ROB). The reduction model includes along with linear members the third degree polynomial to correct the aberrations of the lens. The internal accuracy of the measurements was about 1 micron; it is equivalent to 20 mas for the plates obtained by 26-inch refractor.

The results for astrometric reduction for 40 plates with Saturnian's satellites and Pluto are presented at this paper. Average accuracies of obtained positions are 0″.14 in RA and 0″.09 for Pluto; 0″.24 in RA and 0″.25 in DEC for Enceladus and Hyperion; 0″.15 in RA and 0″.08 in DEC for other major Saturnian's satellites.

The presented method of digitizing the photographic plates is suitable for scientific aims and has several advantages: the size of the area of digitizing photographic plates from 75x90 mm, high speed of digitization - at least two plates per minute, mobility of device and low cost.

Equipment

The "Mobile Device to Digitize" (MDD) is just a work title for the simple installation, which consists of stand, plate holder, camera holder, digital camera body, lens and LCD monitor as a backlight. Digital Camera Canon EOS 5D Mark II has a full-frame CMOS-detector of size 36 × 24 mm with an resolution of 21.1 million pixels, ISO - 100-6400, bpp - 42.

We used the four-lens anastigmatic "Jupiter 21M". The characteristics of lens are following: focal length - 200 mm, aperture - 1:4.0 to 1:22, field of view - 12°, resolution (center/edge) - 40/30 lines/mm.

Camera, lens and holder of plate are mounted on a rigid vertical stand that fixed to the main wall to reduce vibrations during process. LCD monitor used as a backlight is located outside of depth of lens focus.

Image processing and measurements

Digitized images were converted from 16 bit RAW to 16 bit TIF using the software shipped with Canon camera. Then the images were converted to 16-bit grayscale by summing the values in the RGB-channels for each pixel. The measurement of digitized images was made with the program package IZMCCD (Izmailov, 2005). Centers of stars images are determined using a profile specified by the Lorenz function (Franz, 1973).

Calibration

Digitized image is distorted due to aberrations of the camera lens. Camera calibration was performed to study the systematic and random errors, to determine the scale and inclination and non-orthogonality of the coordinate system axes. The calibration template had been digitized and measured with ROB digitizer DAMIAN during the year 2008. This template is a photographic plate (16 x 13 cm) with 200 round marks, which are made by photographic method. Size of mark is about 250 - 300 microns. Measured with ROB digitizer mark coordinates were adopted as standard and were used for comparison. Dependences of systematic errors ΔX, ΔY [mm] on measured coordinates X, Y [px] are demonstrated on Fig. 1. Maximal values of systematic error were 0.0900 mm for X and 0.1000 mm for Y.

It is not enough to use the linear reduction model with six parameters by reason of systematic errors due to mainly by lens aberrations. It was found that model using the third degrees polynomial corrects the systematic errors in a best way. Maximal residuals after using the reduction model were 0.0017 mm in X and 0.0017 mm in Y on the edges of image. Standard deviations in X and Y are σ_{1X} = 0.56 μm, σ_{1Y} = 0.63 μm, number of measurements used for deriving the error estimations was 30. The distribution of residuals is random (see Fig. 2), and thus, the result of the reduction (the coordinates of the star images centers, mm) does not include the systematic errors.

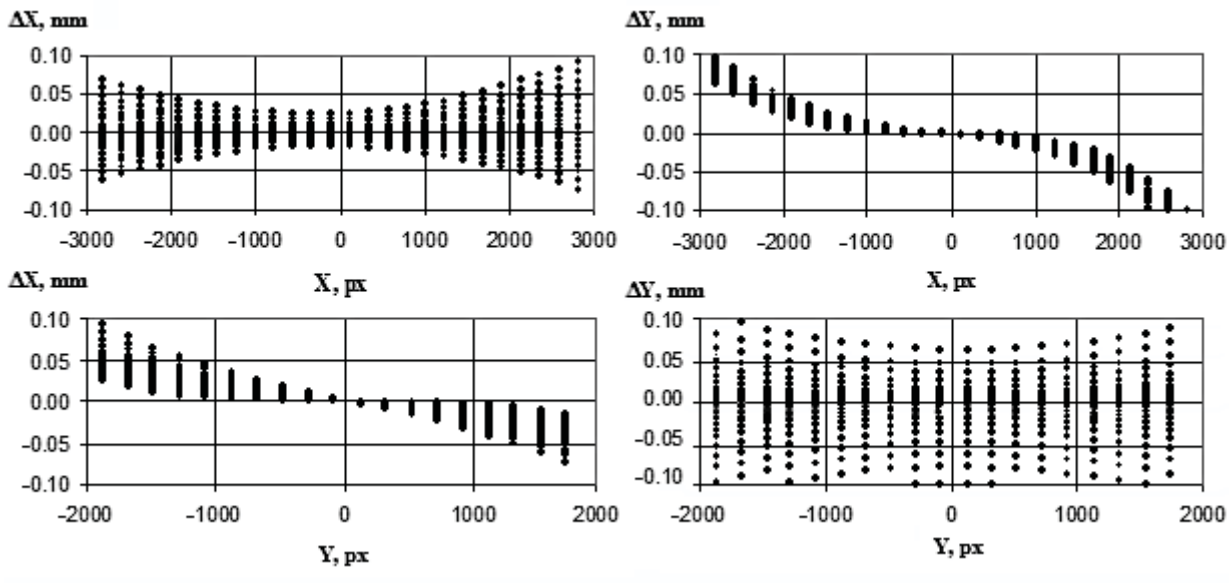

Figure 1. Systematic errors before correction.

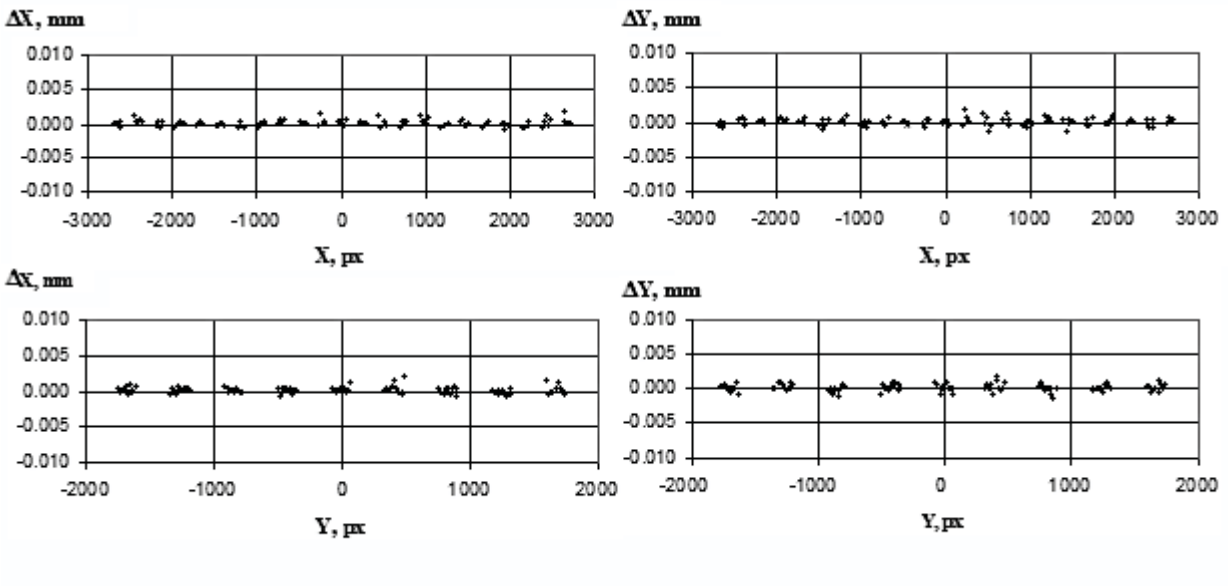

Figure 2. The residuals ΔX(x), ΔX(y) and ΔY(x), ΔY(y).

Stability

Stability of digitization and measurements were investigated using template. The template was multiply digitized in different positions and measured. The Turner's method was used for measured coordinates comparison. Results are shown in Table 1.

Table 1. Comparison of measured coordinates of template, that was multiple digitized in different positions.

Conditions of digitization	σ_x [μm]	σ_y [μm]	N
without plate offset	0.37	0.39	10
with plate offset	0.49	0.50	10
with rotation on 180 deg	0.73	0.88	10
with rotation on 90 deg	0.63	0.63	10

Method test

The determination of trigonometric parallax for visual double star ADS 8002 was chosen to prove this method. This task was selected taking into account the following points. First, this is the most complicated task in photographic astrometry and the measurement accuracy is critical. For example, if there is an interval of measurement accuracy 1.0 - 1.5 microns, 1.0 microns - an satisfactory accuracy for this task, the accuracy of 1.5 microns is not sufficient. Second, only the accuracy of measurements defines the final precision of results. In case of equatorial coordinates, the determination of the accuracy is influenced with reduction error, catalog errors and accuracy of measurements. Third, this series has been previously digitized and measured with a semiautomatic measuring machine with visual guidance "Askorecord", with automatic measuring machine "Fantasy"(Polyakov et al, 1994) and by scanner Microtek Scan Maker i900 using two methods (Izmailov, 2000, Khrutskaya, Kalinin, 2012) and results of all measurements were compared. Comparison of accuracies of different methods of measuring parallactic series of ADS 8002 is given in Table 2.

Series of ADS 8002 observations consists of 55 plates obtained with Pulkovo 26-inch refractor (D = 65 cm, F = 10413 mm, scale = 19.8″/mm). The five stars located within area 70x90 mm were used

as stars of comparison for trigonometric parallax determination. The number of exposures on the plates was varied from 5 to 20. During the digitization the plates were placed at a distance from the camera so 1 px of the final image corresponded to 21 microns on the plate. The calibration template was digitized before the series of plates.

To select the optimal shooting mode, the series was digitized and measured 20 times. The following conditions were varied: the spectral range, aperture, and exposure. Two lens 300 mm «TAIR-3» and 200mm «Jupiter 21 M» were compared and «Jupiter 21 M» had been showed the better quality of star images.

Table 2. The standard deviations for measured coordinates of double star components.
N is number of plates used for comparison.

	N	mean	ADS 8002 A		ADS 8002 B	
		σ	σ_X [μm]	σ_Y [μm]	σ_X [μm]	σ_Y [μm]
"Fantasy"	25	0.81	0.77	0.83	0.97	0.66
"Ascorecord"	25	1.57	1.34	1.72	1.29	1.95
"Fantasy"	36	0.84	0.81	0.82	1.06	0.68
Scanner (by I. Izmailov)	36	2.95	1.88	3.72	2.57	3.65
"Fantasy"	30	0.77	0.67	0.75	1.00	0.64
Scanner (by S. Kalinin)	30	1.80	1.51	1.56	2.61	1.49
"Fantasy"	40	1.03	1.00	1.11	1.19	0.83
MDD (presented method)	40	1.02	1.03	0.95	1.07	1.01

If we adopt the accuracy of the "Fantasy" as a unit of one, the relative accuracies of other methods of measurement are the following:

"Ascorecord"	1.94
Scanner (by I. Izmailov)	3.51
Scanner (by S. Kalinin)	2.33
"Fantasy"	1.00
MDD	0.99

And the final results of our measurements and calculations are the trigonometric parallaxes of components of visual double star ADS 8002:

with the automatic high-precision measuring machine "Fantasy"	with the presented method based on plate digitization by Canon camera:
π_A = **43.25 ± 6.3 mas**	π_A = **51.22 ± 6.6 mas**
π_B = **31.90 ± 7.5 mas**	π_B = **30.90 ± 6.6 mas**

Digitization and measurements of Saturn's and Pluto plates

The 24 plates of Saturn were obtained in 1975 during 10 nights with 26-inch refractor. It were used the different emulsions and exposures for satellite of different brightness: ORWO NP 27 (1^m), ORWO NP 27 (3^m), KODAK 103ad (3^m).

We had digitized the template first. It is necessary to do every time before digitizing of any series. The digitized template and plates were measured with software package IZMCCD (Izmailov, 2005). Measurements of template were used for calibration. Measured coordinates x,y [px] were corrected for distortion and transformed to standard coordinate system [mm]. After that the astrometric reduction by Turner's method was made using the TYCHO2 as reference catalog (9-12 reference stars for each plate).

We compared satellites positions with their ephemeris. All theoretical positions of Saturnian's satellites were taken with Natural Satellites Ephemerides Server MULTI-SAT (Emel'yanov, 2008). The

ephemerides were calculated according to theory. The external accuracy of observations was estimated using the dispersion of O–C differences. The external accuracy depends on distortions caused by the atmosphere and on characteristics of the telescope and detector system. Also it depends on reference stars position errors and reduction errors. The mean values of O–C differences, errors of mean (ε_α, ε_δ), and root mean square errors (σ_α, σ_δ) are given in Table 3 for the second to eighth satellites, in seconds of arc.

Table 3. Mean values of (O-C) residuals, standard deviation σ, arcsec, and average errors of mean positions ε, arcsec. N – number of obtained individual positions.

Satellite	N	Mean $(O-C)_\alpha \cdot \cos\delta$	Mean $(O-C)_\delta$	$\sigma_{(o-c)\alpha}$	$\sigma_{(o-c)\delta}$	ε_α	ε_δ
Enceladus	8	-0.16	0.09	0.24	0.27	±0.15	±0.12
Tethys	23	-0.04	-0.01	0.16	0.06	±0.06	±0.03
Dione	52	-0.03	0.04	0.13	0.10	±0.04	±0.04
Rhea	67	-0.07	0.01	0.12	0.09	±0.04	±0.03
Titan	82	-0.12	0.02	0.16	0.08	±0.05	±0.03
Hyperion	8	0.00	-0.07	0.24	0.22	±0.30	±0.16
Iapetus	71	-0.07	-0.01	0.16	0.09	±0.07	±0.04

Plates for Pluto were obtained with Normal Astrograph (D = 33 cm, F = 3467 mm, scale = 59.56 "/mm) in Pulkovo. The 16 plates with Pluto were digitized using the Mobile Digitizing Device (MDD) to test of a new digitizing device. Each plate was digitized four times. The average values coordinates (X, Y) were taken for reduction. The random measurement error was 0.6 micron for both coordinates. The measurement of coordinates (X, Y) was made using the software package SCANSOFT (Khrutskaya et al, 2012), which was slightly modified.

These plates were also digitized with the DAMIAN digitizer of ROB (De Cuyper, Winter, 2006) earlier in 2008 year. Now, the software package SCANSOFT can be used to process the plates, which were digitized by flatbed scanners, the DAMIAN digitizer and the MDD. The systematic errors of the MDD were taken into account.

The six-constant method has been used for the astrometric reduction. The UCAC3 was used as a reference catalog. The residual systematic errors (coma, distortion, magnitude and color equations) were taken into account. The results of the comparison of observations of Pluto, obtained from the plates, which were digitized by means of the MDD and the DAMIAN digitizer, with DE405 ephemeris are shown in the Table 4**.** The average accuracy of one Pluto observation using 16 plates was estimated as following:

$\varepsilon RA\cos\delta$ = 143 mas and εDECL = 85 mas for MDD,

$\varepsilon RA\cos\delta$ = 135 mas and εDECL = 91 mas for ROB digitizer DAMIAN.

For comparison, accuracy of one Pluto position, that was estimated using results of 62 plates digitized with DAMIAN, was: $\varepsilon RA\cos\delta$=153 mas; εDECL=107 mas. All plates on the DAMIAN digitizer were digitized only in one position without rotation.

The obtained estimates of accuracy the MDD are preliminary because they were got on 16 plates only. Nevertheless, these results allow us to hope that the accuracy of astrometric reduction will be comparable for both devices.

Nowadays, 64 plates with Pluto (observation period 1930-1960) have digitized using the MDD; the DAMIAN digitizer already digitized 62 of them. Reduction of these plates and their comparison with previous results for DAMIAN digitizer will allow to estimate the accuracy of the new digitizing device more confidently.

Table 4. The comparison of the Pluto's positons and DE405 ephemeris;
O-C differences are given in arcsec.

Date observations	Mobile Digitizing Device		DAMIAN Digitizer	
	(O-C)αcosδ	(O-C)δ	(O-C)αcosδ	(O-C)δ
1953 03 11.872799	-0.15	-0.28	-0.16	-0.24
1953 03 14.872918	-0.14	-0.11	-0.16	-0.21
1953 03 15.878498	-0.18	-0.16	-0.30	-0.11
1954 03 21.803217	-0.45	-0.19	-0.41	-0.17
1954 03 31.827854	-0.17	-0.17	-0.17	-0.10
1954 04 20.844578	-0.16	0.02	-0.21	0.01
1955 03 23.818502	-0.04	-0.34	-0.16	-0.22
1955 04 8.802863	-0.36	-0.24	-0.35	-0.19
1955 04 24.849207	-0.27	-0.13	-0.33	-0.13
1956 03 16.883332	-0.15	-0.24	-0.21	-0.26
1956 03 31.809133	-0.17	-0.26	-0.23	-0.25
1956 04 30.885813	-0.16	-0.19	-0.22	-0.13
1957 03 20.891077	-0.33	-0.07	-0.33	0.01
1957 03 25.863574	0.11	-0.16	0.14	-0.14
1957 03 29.867889	-0.09	-0.09	-0.14	-0.16
1957 04 1.809141	-0.09	-0.13	-0.13	-0.28

Conclusions

The presented method of plate digitization provides a good accuracy of measurements and has some advantages. Main disadvantage of method is the low resolution of digitized image: 1 px corresponds to 21 μm of plate. But it does not affect on reduction result because measurement accuracy is better then reduction errors. So we may conclude that digitization of plates with Canon camera are suitable for measurements for astrometric goals, if it is impossible to digitize and measure the plates with high-precision measuring machines.

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