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High-Precision Measuring Scale Rulers for Flatbed Scanners

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Abstract. Digitization and image processing of the astronomical plates for an astrometric series using flatbed scanners do not preserve high metrological characteristics of the readout information, due to construction features of these devices. The proposed application of the high–precision measuring scale rulers allows to transform a flatbed scanner into a efficient measuring device whose precision measurements characteristics will be comparable with such specialized astrographic measuring machines as of Carl–Zeiss "ASCORECORD" type.

1 Introduction

Recently the international astronomical community stressed on the problem of preservation of the photographic observational materials having almost one and a half century history [1]. The Automated Measuring Complexes (AMC) such as GALAXY, SUPER–COSMOS, APM, PPM, PMM, PDS's, LAMA etc. worked successfully to solve this problem [2–5], but at present most of them stopped their activities. These classical plate digitization systems worked in several astronomical institutes were used successively to digitize thousand astronomical plates from the basic astronomical photographic surveys like Palomar Sky Survey, CdC, ESO, UKSTU, etc. In the same time it was clear that only with these devices it will be not possible to digitize, process and preserve the entire amount of world plate collections reached of more than 2 200 000 astronomical plates [6] (http://www.skyarchive.org/catalogue.html#Cat50).

The Pulkovo Observatory Plate Archive possesses almost 50000 astrographic negatives and constitutes about 10% of the wide-field astronomical photographic observational materials accumulated in the country. In the period 2000-2004 the first stage of the project aiming digitalization of the entire contents of the Pulkovo plate collection and its saving on the electronic data media has been carried out at the Laboratory of Scientific Measurements (LASM) of the observatory [10]. In the frame of this project more than 35000 plates were digitized using the flatbed scanners of UMAX-1200 and UMAX-2400S types equipped with transparency adapter module (Figures 1, 2). The scanning operation has been performed with the resolution of 600 dpi to 1200 dpi. The digitized images of the plates like preview are the basic data for the second stage, i.e. for the further high-precision digitalization of the entire plate collection to be carried out partly by using also the Automated Measuring Complex (AMC) “FANTAZIA” (Figure 3). We estimate that more than 10 years are needed to complete such large scale project. Similar work has been initiated in the period 2000-2004 for the Russian astronomical photographic archives at the Institute of Astronomy of the Russian Academy of Sciences and Zvenigorod Observatory, the Sternberg Astronomical Institute of the Moscow State University [7–9]and others. In these cases the digitalization is planned to be carried out by using also flatbed commercial scanners, like EPSON 1640XL and CREO. The high resolution digitization process of the flatbed scanners used, however, does not guarantee saving all characteristics of the photographic material due to the construction features of scanners, i.e. because of lack of the light detector (the CCD-line as usual) positioning check during the scanning process.

2 Construction Features of Flatbed Scanners

A scanner for the digitization of transparent carriers (Figure 1 a-b) is composed of two functionally similar blocks, i.e. of the scanner (left) and the adapter for transparent carriers (right). The systems for positioning of carriages with an transparency adapter (Figure 2-left) and with the CCD light detector (Figure 2-right) are mounted in two blocks and during the scanning process are syn-

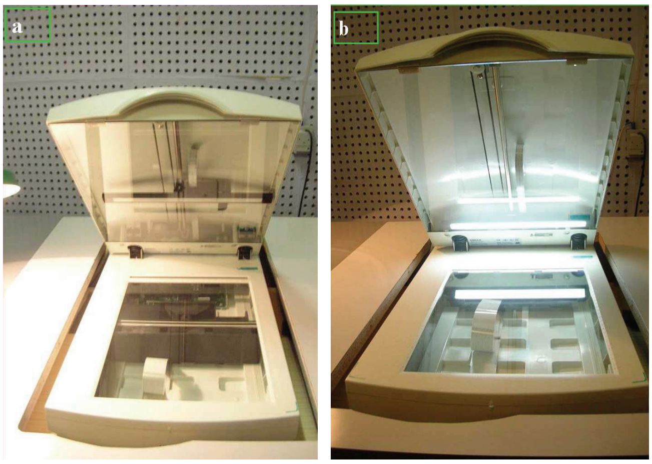

Figure 1. UMAX 1200 scanner with the transparency adapter (a) and picture of the scanner with “light-on”(b).

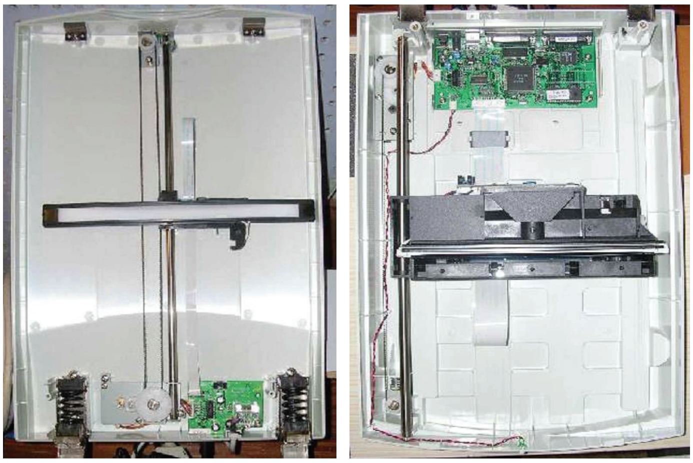

Figure 2. The positioning systems of the scanner halogen lamp (left) and the CCD-line light-detector (right).

chronically moved. The illuminator is equipped with the gas-discharge lamp of high luminosity, and the light detector consisting of the mirror-lens system, slit diaphragms, and a CCD-line (ruler), and image being measured line-by-line projected onto it.

Both carriages (with lamp and CCD-detector) are moved by the step-motors in the step by step mode, each of them being parallel shifted. The parallelism is secured by bushings which are impressed into the carriages and sliding along the steel staves. The situation of the staves of the illuminator and of the light detector is different, i.e. they are close to the middle of the carriage for the former, and to one edge of it for the latter, the other edge being free and moving on the horizontal shelf leaning on a roller.

The application points of the traction are situated near to the bushings. As a mover the cogged rubber belt is used. The carriage position is defined by a number of the motor step. The scans are formed at the pause instants in the movement. The scanning step along the X-axis is defined, therefore, by the optical characteristics of the device, whereas that along the Y-axis by the mechanical ones. The working planes of the scanner and of the adapter are confined by glass slabs, the volumes of both blocks being protected considerably from the soiling from outside.

3 Sources for Scanning Errors

The full list of the scanning error sources can be found below. For the requirements to the astrometric material, i.e. within the sub-micron value range, the

Figure 3. The AMC "FANTAZIA".

guides should be considered as non-rectilinear ones, bushings and gears as having a considerable backlash, pulleys and rollers as eccentric ones, the cog-belt as the stretchable one, the position of a light-detector by the digitization of the lines of an image as non-stable one, etc. The most serious drawback of scanners is, however, the lack of the check of a light detector position during the scanning process. One should note that the safeguarding the astrometric quality of the material to be scanned is not included into a list of problems which are to be solved by using the non-specialized scanners. From this point of view the drawback mentioned above is not a drawback as such. Actually the integral error generated by the causes listed above does not exceed in average 4 to 7 microns, i.e. it is related to sub-pixel effects even if a very high resolution is given, for example, 2400 dpi, corresponding to a scanning element of slightly more than 10 microns. The exceptions are errors delta y in the domain $y = y(\max)$ capable of reaching the values $|Dy|$ of approximately $20 \div 30$ mm.

The present paper deals with the metrology testing of a scanner based on measurements of division positions on four scales taken from the Carl-Zeiss "ASCORECORD" type measuring machines. All the four scales were placed at the working glass surface of the scanner and scanned repeatable by the resolution of 1200 dpi with time-intervals between 0 to 30 minutes. 12 files in total were obtained, each comprising 115 MB of the digitized copies of A 4 format images. In this experiment the scales were considered to be the ideal ones. Their errors were not investigated but supposed to be equal to zero. There was no accounting for thermal dilatation-compression of the scales. There was no accounting for distortions due to the light-detector optical system, they were considered to be constant at this stage. The main consideration has been given to the mechanics of the device. The analysis of the measurement results made possible to find two groups of non-authorized movements of the light-detector carriage, i.e. shifts and skews leading to the image sub-pixel distortions which could be detected by the position measurements of its individual elements only. Omitting the detailed analysis of the error forming processes the main of them will be enumerated, their sources are indicated and value estimates are being given.

3.1 The X-coordinate errors:

3.1.1 The non-rectilinearity, or the flexure of the guide in the vertical plane, $|\triangle z| < 30$ mm due to the CCD-line detector would consequently be inclined with respect to a scanned astronomical plate by the angle $\psi \approx \triangle z/L$, $\psi \ll 1°$, the error $\triangle x \approx h\psi$, where L is the length of the CCD-line, $h \approx 45$ mm is the distance of the plate from the prism.

3.1.2 The non-rectilinearity of the guide in the horizontal plane by the $\triangle x$ value which leads consequently to the shift of the CCD-line by $\triangle x$, $|\triangle x|_{max} < 10 \div 15$ mm.

3.1.3 The eccentricity of the driven guide-roller on the loose end of the light-detector carriage, the effect being the same as above in 3.1.1.

This is the main list of causes (the optical ones being not accounted for) with leading to the image distortion along the X-coordinate. The image scan-out along X being performed by the CCD-line, the shift of a line as a whole without change of mutual positions of its individual elements is to be considered as a characteristic error. On the contrary, the mechanical scan-out is generating the Y-distortions connected with the skews of the carriage while moving and with the positioning errors.

3.2 The Y-coordinate errors:

3.2.1 The non-rectilinearity of a guide in the horizontal plane by a value of $\triangle x_b$, where b is the distance between driving bushings (see Figure 2-right). The effect is the ruler skew by the angle $\varphi \approx \triangle x_b/b$, $\varphi \ll 1°$, $|\triangle x_b|_{max} < 10 \div 15$ mm, $\triangle y \approx x\varphi$, $|\triangle y|_{max} < 3 \div 5$ mm. The error magnitude increases with the distance from the guide axis.

3.2.2 The bushing skews contribute mostly into the total error $\triangle$y which leads to the greater ruler skew than described above in 3.2.1.: using direct measurements made by use of a micro-metric indicator it is shown that the errors reach 25 microns and more in the zone of high X values.

3.2.3 The positioning errors (the carriage does not come out into a specified position) are related to the slackness of the power gear cog-wheels, the

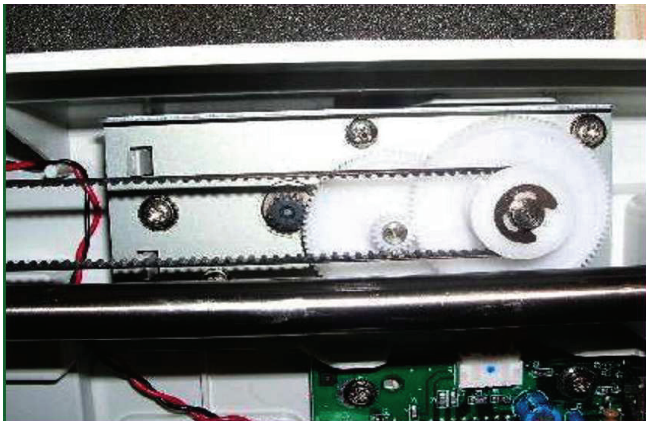

Figure 4. The power gear, cogged belt drive and a guide.

eccentricity of the tension pulley and the stretching of the cogged rubber belt (Figures 4-6). Errors of this kind reach maximum values ranged as $20 < |\triangle y|_{max} < 30$ microns in the high Y-value zone, the situation getting worse as far as the mechanical part elements wear out.

The values given for the plate position measurements with a scanner, more correctly speaking, for the measurements of images distorted while being scanned, are in accordance with the estimates obtained by other authors and by use of other techniques [11, 12].

Attempts to use scanners for digitization of plates have been undertaken from the very time of the appearance of scanners. In the mid of 1990s at the LASM Pulkovo even a manual scanner had been used to obtain the provisory coordinates of objects on plates. In spite of a fast progress in the domain of scanning devices and successful scanner application for solution of a narrow class of astrometry problems [11] this technique has been considered and applied as an auxiliary equipment only because of availability of the measuring complex “FANTAZIA” at Pulkovo. The ever growing interest, however, for potential use of scanners in a non-profile sphere, i.e. for creation of electronic astrometric data collections, has prompted us to propose a cheap and, hopefully, the efficient version of additional outfitting the scanner and converting it into a measuring device with high metrological features, based on the accumulated experience in digitization of the plates and on availability of such a precision measuring engine as AMC “FANTAZIA”.

It seems to be that this problem would easily be solved thanks to modern development of technologies in electronics and micro-mechanics, and to availability of position mini-sensors, and it is actually so if the cost of the sensors is not

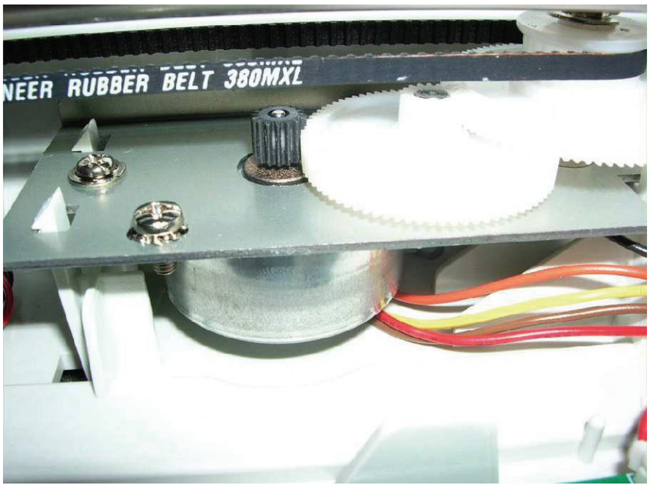

Figure 5. The electric step-motor and the power gear cog-wheels.

accounted for, they exceed the cost of a scanner itself by one order of magnitude. The cheap solution proposed is resting upon application of the specially bench-marked scales converted into a highly precise instrument by a preliminary investigation and their certification using the expensive precision sensors.

Figure 6. The tightening pulley, the cogged rubber belt, mounted of the guide.

4 Hindrance Sources on Images

It would be necessary and suitable to mention the most frequent hindrances on images. As a rule, their sources are scratches, nap, dust particles on the object-glass, and the particles of the worn-out scanner parts which are the most annoying and hardly removable hindrance. The first group of factors could be minimized by keeping the working room clean and by personal wearing the protective clothing. Nevertheless, even in minimum quantities the exterior impediment sources may cause concern because even that what seems to be not only unnoticeable but hardly distinguishable on usual photographs will form pseudo-images on plates which will often be not to tell from star images. Before scanning the plates should be, therefore, washed with the spirits or the spirit-ether mixture of the glass-side, and blown with air from the air-pear or swept with a very soft brush of the emulsion-side, and the object-glasses of the scanner and of the adapter as well should be wiped with the suede.

Yet more complicated matters stand with the inner particle sources. In our case these are the particles of the black plastic coming from the spring-loaded adapter supports and those of the white plastic arising from the axles of the tension pulleys (Figure 7).

Both, the exterior and interior particles are moving on the inner surface of object-glasses under influence of the electrifying due to the scanner work. They are removed with a vacuum-cleaner which may require a partial disassembly of the device.

And, finally, a representative of the third hindrance group having entered the vocabulary of the computer technique and its history from the very first days is a bug (Figure 8) which has been encountered in our practice only once, being extracted from the entrails of the scanner and having caused no harm either to the digitized images or to the hardware.

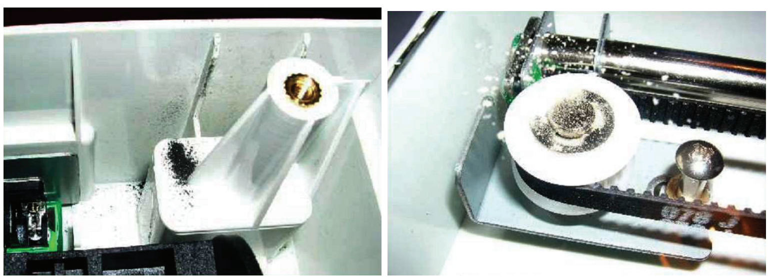

Figure 7. The plastic particles of the worn-out adapter supports which have got into inner space of the scanner (left), plastic particles of the worn-out axle of the tension pulley sticking to the electrified object-glass of the adapter (right).

Figure 8. An example for a real "bug" found inside the scanner.

The best solution of the hindrance problem consists seemingly in the withdrawal of the object-glasses from the scanner and their replacement with a cassette for attaching an astronomical plate of the lower part of the device, i.e. of the side of the light-detector block, and the mount of narrow glass rulers or wire rope guides into the adapter which will support the illuminator carriage edges from below. So, the two surfaces will remain out of six ones subjected to soiling, i.e. the glass and the emulsion of the plate itself.

5 The Bench-Marking of a Scale

The problems related to the use of flatbed scanners for the astrometric work and methods of their solution are known. These are, first, the method of measurements by use of the one-coordinate devices which is known since long times and consists in the twofold scanning of an plate with the 90-degree turn, the results of the measurement along the precise axis being combined in the consequent processing, and, secondly, the method dealing with mixing-up the standard markers with precisely known positions into a starting image, the results of the measurements of the material under investigation being reduced to the system of the markers. Both methods have accurately been investigated in the paper [11].

We propose the third method based on applying two standard scales (Figure 9). The scales are located along the edges of the image under consideration and scanned together with it. Strictly speaking, this method is an advanced version of the second approach but appears to be more efficient and to have no drawbacks of its forerunner, i.e. it would make it feasible to directly measure errors of every individual scan with no reductions of measurements using the limited number of standard markers; it will make it possible to compensate in full detail for an image distortions by direct computation of the position corrections for every image element. It is assumed that the CCD-line is solid and non-flexible, and the position of its pixels is invariable with respect to its basis, that the distortions

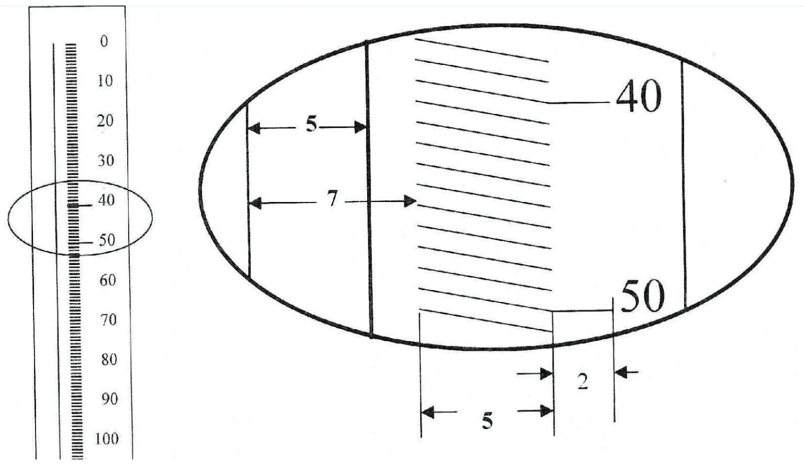

Figure 9. A scheme of the bench-marking of a standard scale for a flatbed scanner.

due to the light-detector optical system are constant, these assumptions are valid on the micron accuracy level.

Composition of divisions and lines of the scale bench-marking allows to monitor a position of each scan along both axes. The solid vertical lines (the guides) of the two scales serve for determination of the CCD-line shift along the X-axis. The evolutions of the light-detector along Y-axis are stated with respect to the slanted divisions which are cut in such a way that any horizontal line for any Y-value always have no less than one intersection point wit the division system. In other words, the CCD-line will have marks on divisions of both scales in its any position in the limits of the scanner working field, so that under the assumption made a position of any element of a digitized image may be determined on an photographic plate with respect to the starting one. Moreover, the use of slant divisions as the vernier allows to significantly increase the accuracy of the light-detector position along the Y-axis.

The scales are manufactured on the glass base by scribing marks using the photolithography technology. The photolithography is applied to form the metal film relief. In our case it is the chromium film 0.1 mm thick deposited by the vacuum sputtering on the surface of a glass ruler. The photolithographic method is based on the ability of some forms of high-molecular compounds to change their properties under influence of the light action. If the films of these compounds (the photoresists) are stable with respect to the etching agents applied in the photolithography process they may be used for protection by the relief formation. The exposure of the photoresist film deposited on the surface of the metal-coated glass ruler is made through the glass mask with a system of transparent and opaque lines which are the future line elements of a ruler. After the subsequent development useless parts of the resist film are removed from the base, and the protecting mask is formed with a pattern of a size corresponding to the design on the mask. The ruler mask is manufactured by means of the computer-controlled image optical generator. The generator makes use of a fine-focused light beam which is scanning the plate area according to a given program and forming a structure of the designed topology.

The minimum size of the image elements is equal to several units of micron by the positioning accuracy of from 0.2 to 0.5 μm. The breadth of lines and that of the scale solid line (Figure 9) have been chosen, however, to be equal in the interval 30–50 μm, respectively, to avoid the sub-pixel magnitude effects when working with scanners with the resolution of 1200–2400 dpi, i.e. for sizes of the image elements ranging from 20μm to 10 μm.

6 The Scale Certification

The manufactured scales are being certified by means of highly accurate measurements of positions of slant lines and the solid scale line (the guide) using AMC “FANTAZIA”. The electronic certificate is done for each scale, being a file containing the corrections of the guide for non-rectilinearity, the line coordinates relative to the guide, the coordinates of singular points, i.e. hindrances, flaws, increased thickness and gaps in marks and lines. The scale certificates are used by the program for correcting the digitized image.

7 Application of the Scales

The glass scales are laid parallel with the plate edges by sufficiently free tolerance. The difference between the scale zero-points and their deviation from the Y-axis direction is determined and compensated by a program while processing. The plate is scanned together with the scales, constituting the unified digital image with them. The image correction is based on the scale measurements and done whether directly by the position measurements of objects or on the stage of preparation of an image for measurements, its corrected version being obtained. There are “pro” and “contra” arguments for each approach. In the first case none image element is changed, the file contents being untouched, every point constituting the object under measurement takes part in the measurement process having its own density value and precise coordinates as well. As to the second approach, a new file is created, the elements being the results of the bi-linear or bi-cubic interpolation which leads to some smoothing of images imperceptible practically on objects which are the characteristic ones for astro-plates. This processing version is efficient when extracting individual images from the common picture or when several images are commonly processed because the corrections are introduced into the coordinates of everyone of them.

8 Conclusions

In the present paper we discuss the main sources of measurement errors due to the device construction limits during the astronomical plate digitization using the novel flatbed scanners. They may raised when we performed large scale plate digitization, further image processing and measurements on the way of creating precise data sets of electronic copies of the astronomical plate collections stored at Russian astronomical observatories and others observatories. In view of the actual character of the problem we decided to publish here a preliminary information before the detailed investigations of the proposed techniques - application of precise glass rulers together with an additional equipment and software package for the flatbed scanners which can be additionally completed in order to spare the efforts and improve the results which can be extracted from the digitaged astronomical plates.

Acknowledgements

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References

[1] *The IAU 24th GA B3 Resolution* (2000) “The Safeguarding the information in photographic observations”.

[2] N.M. Pratt (1970) *Automation in Optical Astrophysics, Proceedings of IAU Colloq. 11, held in Edinburgh*, 12-14 August, 1970. Edited by H. Seddon and M.J. Smyth. Publ. R. Obs. Edinburgh 8, 1971, p.109.

[3] J.R. Pier and D.G. Monet (1993) *The USNO Precision Measuring Microdensitometer Project to Measure the Two Epoch Plate Sets of the Palomar Observatory Sky Survey*, Workshop on Databases for Galactic Structure. Eds. A.G.D. Philip, B. Hauck and A.I. Upgren, L. Davis Press, p. 161.

[4] N.M. Pratt (1977) *The COSMOS Measuring Machine*, Vistas in Astronomy, Pergamon Press, v. 21, p. 1.

[5] E.V. Poliakov, A.G. Gerasimov, Yu.D. Pikin, A.V. Savastenia, A.V. Sokolov (1994) *Izmeritelnaia Technika* **.3** 9.

[6] M. Tsvetkov (2006) *Virtual Observatory: Plate Content Digitization, Archive Mining and Image Sequence Processing* , iAstro workshop, Sofia, Bulgaria, 2005, Eds. M. Tsvetkov, V. Golev., F. Murtagh, R. Molina, ISBN-10 954-580-190-5, p. 10.

[7] N.N. Samus, L.A. Sat, S.V. Vereshchagin, A.V. Zharova (2006) *Virtual Observatory: Plate Content Digitization, Archive Mining and Image Sequence Processing* ,

iAstro workshop, Sofia, Bulgaria, 2005, Eds. M. Tsvetkov, V. Golev., F. Murtagh, R. Molina, ISBN-10 954-580-190-5, p. 103.

[8] http://www.sai.msu.su/groups/cluster/gcvs/digit/preprint.htm

[9] http://skanlab.narod.ru/

[10] E.V. Poliakov, H.G. Kakaeva, I.I. Kanaev, T.N. Pugach (2002) *Izvestia GAO RAN* **216** 241.

[11] I.C. Izmailov (2000) *Izvestia GAO RAN* **214** 533.

[12] C. Barbieri, C. Blanco, B. Bucciarelli, R. Coluzzi, A. Di Paola, L. Lanteri, G.-L. Li Causi, E. Marilli, P. Massimino, V. Mezzalira, S. Mottola, R. Nesci, A. Omizzolo, F. Pedichini, F. Rampazzi, C. Rossi, R. Stagni, M. Tsvetkov, and R. Viotti (2003) *Experimental Astronomy* **15** 29.