Serdica J. Computing **6** (2012), 77–88

Serdica
Journal of Computing

Bulgarian Academy of Sciences
Institute of Mathematics and Informatics

TECHNOLOGY FOR SCANNING ASTRONOMICAL PHOTOGRAPHIC PLATES*

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Abstract. Here we describe the technology and the experience during the astronomical photographic plate digitization with flatbed EPSON scanners. More than 275000 plates in different observatories in Europe were digitized with such scanners last decade.

1. Introduction. Astronomical photographic plates constitute glass coated on one side with a dry emulsion of silver bromide. As light detectors and media for information storage, they replaced visual astronomical observations and marked the epoch of photographic astronomy that began in the 1870s and lasted for more than 130 years. Many astronomical discoveries were made on the basis of photographic plates used in the observations. Moreover, astronomical photographic plates stored in observatories or relevant institutions continue to be used for different astronomical tasks, especially such ones which need long time

ACM Computing Classification System (1998): J.2.

Key words: astronomical photographic plates, plate digitization.

*This work is supported by the BG NSF DO-02-273 and DO-02-275 grants and DFG grant STE: 710/6-1,20.11.2009.

series observations. The astronomical photographic plates are typical examples of scientific heritage in need of preservation for future use. The only way to store the information from the plates is their digitization. By working with a digital copy of the plate the fragile glass is better preserved. The aging of the emulsion and the following loss of information are other reasons for the digitization of the plate. On the other hand, the digitization of the plate gives quick and online access to the image information on the plate.

2. Plate digitization worldwide. Table 1 summarizes the data on 282000 wide-field plates already digitized in Europe with flatbed scanners with resolutions better than 20 mic/pix.

Table 1. Scanned European plates with high resolution

Observatory	Number of scanned plates	References
Sonneberg	215000	Kroll [1]
Pulkovo	40000	Kanaev et al. [2], Poliakov et al. [3]
Hamburg	8000	Groote [4]
Vatican	5433	Omizzolo [5]
Tautenburg	4228	Brunzendorf and Meusinger [6]
Asiago	4000	Barbieri et al. [7]
Buyrakan	2000	Cirimele et al. [8], Mickaelian et al. [9]
Potsdam	1500	Tsvetkova et al. [10], Enke et al. [11]
Bamberg	1000	Tsvetkov et al. [12]
Konkoly	600	Tsvetkova et al. [13]
Heidelberg-ARI	344	Schmadel [14]

In Harvard Observatory about 21000 plates were digitized with the new DASH scanner technology [15].

Briefly, at present about 303000 wide-field plates have been digitized already with flatbed and new technology scanners. Some of the plates have only been digitized at low resolution (Table 2).

In Table 3 some parameters of the most-used EPSON flatbed scanners are presented: Optical density (Dmax), Color depth (bit internal/bit external), Grayscale depth (bit internal/bit external), Maximum hardware resolution (dpi).

Table 2. European plates scanned only at low resolution

Observatory	Number of scanned plates
Bucharest	5000
Bamberg	2000
Belgrade	2000
Sofia	1500
Moscow-Zvenigorod	1000
Brussels	600
Cluj	200

Table 3. Parameters of the most-used EPSON flatbed scanners

EPSON Scanner	Optical density (Dmax)	Color depth (bit int./ bit ext)	Grayscale depth (bit int./ bit ext.)	Resolution (dpi)
EXPRESSION 1640XL A3	3.6	42/42	14/14	1600×1600
EXPRESSION 10000XL A3	3.8	42/42	16/16	2400×4800
PERFECTION V700/750 PHOTO A4	4.0	42/42	16/16	4800×9600

3. Scanning parameters. When choosing the scanning parameters, we have to account for the purpose of the digitization of the plate—whether it is done for quick plate visualization or for real astrometric or photometric investigations. For quick visualization the possibility is to examine visually the appearance of the plate and to make a preliminary judgment on the usefulness of a certain archived observation for the intended purposes, as well as easier web accessibility. The plate preview scans are done at low resolution, sometimes even with a digital camera and light table. Another purpose of the plate previews is to store the important marks made by the observer on the plates—observed minor planets, variable stars, comets, standard stars, etc.

The software used for scanning is:

- For making preview images—Adobe Photoshop or ImageMagick,
- For high-resolution scans—the special software Scanfits by S. Mottola (Barbieri et al. [7]) or VueScan [16].

The scanning of the plate is done at the entire density range (0–255) and Gamma = 1.00 for data standardization. The other scanning parameters are dependent on the astronomical task. The color depth for preview images is 8-bit or 24-bit Color, in order to save the observer's marks made on the plate (sometimes in color). The color depth for high-resolution scans is 16-bit Grayscale. The scanning resolution used (high or low resolution) also depends on the task and sometimes it is a compromise between the astronomical task, the output file size and plate size. For the plate preview the optimal resolution is considered to be 600–1200 dpi; for high-resolution scans as a rule it is 1600 or 2400 dpi.

Regarding the output scan files, the plate preview JPEG files produced through compression at 2000 × 2000 pixels of the initially output TIFF files and the FITS files of the high-resolution plate images, the data for the selected Wide-Field Plate Database (WFPDB) catalogues [17] are summarized in Table 4.

Some of the plates were scanned with a neutral step wedge of type TG21S with 21 grayscale steps (each step is 0.15D in the range of densities 0.05–3.05D) using another software, VueScan, in chronological order: scanning the plate with the wedge, conversion of the TIFF output file to FITS, separation of the plate image from the wedge image and saving them as separate files. The volume of the FITS file obtained in this way is 430 MB for a 16 × 16 cm plate, and 692 MB for a 20 × 20 cm plate. The TG21S step wedge image file is 80 MB.

The choice of the optimal scanning parameters depends also on:

• The scale (S) of the telescope (arcsec/mm), respective to its focal length.

The scale is calculated by S = 206265/f, where f is the focal length in mm. For example, for the 2m Ritchey–Chrétien-Coude telescope in Rozhen with a focal length in the Ritchey–Chrétien focus 16000 mm, it is 206265/16000 = 12.8, or roughly 13 arcsec/mm. Usually when the telescope scale is equal to 60 arcsec/mm, the telescope is called a "normal" astrograph. Normal astrographs are all telescopes of the program Carte du Ciel, with a focal length of 3.48 m. Such "normal" astrographs were designed and used specifically for astrometric purposes, i.e., for accurate measurement of stellar coordinates. Having plates in the WFPDB obtained with "normal" astrographs, Schmidt and Maksutov cameras, and Ritchey–Chrétien telescopes [18] with comparatively long-focus telescopes (more than 200 cm), it is recommended to scan the plates twice with a rotation of 90 degrees. We must emphasize once again that this concerns wide-field telescopes with a scale of 10–100 arcsec/mm. The telescopes with scales of more than 100 arcsec/mm are not usable for precise measurements of celestial coordinates. In such cases, even if we scan the same plate repeatedly with a mode of rotation angle of 90 degrees to avoid a "Vobla" shifting effect due to the lower mechanical precision of flatbed scanners, it will not substantially increase the accuracy of measurements. Such telescopes with large scales (i.e., short focal length) are the wide-field patrol cameras used for sky surveys. However, in the case of Ritchey–Chrétien optical systems and similar ones with a scale of 10–20 arcsec/mm it has to be balanced with the optimal resolution of scanning to avoid falling into extreme artificial increasing of the accuracy. For example, the Great Refractor of the Potsdam Observatory with a scale of 17 arcsec/mm at 2400 dpi (10.58 microns/pixel) resolution we have $17 \times 10.58/1000 = 0.18$ arcsec per pixel, which is unnecessarily precise. When we get 1600 dpi, we have 0.27 arcsec/pixel, which can be considered optimal. When we have 1200 dpi, we get 0.35 arcsec/pixel, which can also be considered usable in general, as the quality of sky images on this plate rarely exceeds 1–2 arcsec during the observations. Scanning at a higher resolution is seldom justified because the properties of the employed emulsion with relatively large grains. Thus our recommendation is to scan such plates at a resolution of 1200–1600 dpi. In the case of the normal astrographs with a scale size of 60 arcsec/mm, 1600 dpi, we get a resolution of scanning 0.9 arcsec/pixel; in the case of 2400 dpi, 0.63 arcsec/pixel, which is also an acceptable high resolution. For telescopes with scales greater than 100 arcsec/mm we recommend using a resolution of 2400 dpi (10.58 microns/pixel). We have about 1.06 microns/pixel, which is on the boundary of reasonable parameters used for the scanning of these plates for astrometric purposes. For these plates the accuracy obtained is in the tenths of arcseconds.

- Type and quality of the employed plate emulsions.

90% of the emulsions of plates included into WFPDB are relatively coarse-grained and highly sensitive. Such are the old emulsions produced in the beginning of the last century—Schleussner, Matter, Lumiere, as well as later ones such as Kodak 103aO, ORWO ZU2/ZU21, AGFA ASTRO (GEVEART), etc. The optical solution of these emulsions is in the range of 20/40 lines/mm (50–25 mic/line). In our case we have a resolution of 25–50 microns per line respectively. According to the image processing such emulsions should be digitized with an optimal size of a half of a pixel, i.e., 12.5–25 microns/pixel.

- Capacity of the flatbed scanners.

The scanning devices used now are made on the basis of advanced technology using CCD line-detectors. The plates can be scanned at 5 to 10 microns per pixel. Such scanners are EPSON type scanners, equipped with a transparency module: Expression 10000XL/1640XL(A3)/ and PerfectionV700/750(A4). These scanners have the option to scan with a resolution of 2400 dpi, corresponding to

25400/2400 = 10.58 microns/pixel. It is also possible to use 1600 or 1200 dpi, which correspond to 15.88 or 21.16 microns/pixel. These are the optimal resolutions used for plate digitization with flatbed scanners for 215000 plates of Sonneberg Sky Patrol [1], or for 40000 plates from the Pulkovo observatory [3] at a resolution of 20 microns/pixel. One should not forget that this resolution is the limit used for previews of such images. The risk to lose some information from the existing patrol plates is compensated by the possibility of fast access of the observational data. Depending on the astronomical task we can scan the plates again with the required accuracy and resolution.

Table 4. Plate Scanning Data

WFPDB Telescope Identifier	EPSON Flatbed Scanner	Plate Size (cm)	High Resolution (dpi)	Preview Resolution (dpi)	Tel. Scale arcsec/ mm	Scan Size TIF/ FITS (MB)	Scan Size r JPEG/ compressed (MB)
POT080	Perfection V700 Photo	16×16	1600	1200 (compressed)	17	193/ 20*	2
POT015	Expression 10000 XL	20×20	2400	1200 (compressed)	137	681/ 70*	3
POT032**	Expression 10000 XL	16×16	2400	1200 (compressed)	60	440	20/ 2
POT032***	Perfection V700 Photo	16×16	2400	1200 (compressed)	60	412	2
BAM10C	Perfection V750 Photo	16×16	2400	1200 (compressed)	339	430	3
HAR025B	Expression 1640 XL	20×25	1600	1200 (compressed)	167	386	2
HAR025B	Perfection V750 Photo	16×16	2400	1200 (compressed)	167	430	2
BAM007	Perfection V750 Photo	9×12	2400	1200	826	183	5
HAM034	Expression 1640 XL	24×24	1600	1200 (compressed)	61	435	11/ 5
MPI080 HAM080	Expression 1640 XL	24×24	1600	1200	86	435	20 4

BON034	Perfection V750 Photo	8×9	2400	1200 (compressed)	151	126	4
BON030C	Perfection V750Photo	16×16	2400	1200 (compressed)	138	430	3
ROZ200**	Expression 10000 XL	30×30	1600	600	13	664	2
ROZ200***	Expression 10000 XL	30×30	1600	600	13	430/ 43	31/ 2
ROZ050****	Perfection V700 Photo	16×16	2400	1200	120	430/ 43	8/ 2
BAO100	Perfection V700 Photo	16×16	2400	1200	97	430	61/ 2
ESO040	Perfection V750 Photo	16×16	2400	1200	54	430	9
OHP040	Perfection V750 Photo	16×16	2400	1200	54	430	9
ESO100	Expression 10000 XL	30×30	2400	1200	67	1670	30/ 2

*) Scan size without wedge—the size of the wedge scan is mentioned separately (T13—20MB and T21S—70MB, Danes-Picta transparency neutral gray 13- or 21-step wedges [19].
**) Scan with Scanfits software using the standard EPSON driver.
***) Scan with VueScan driver and the new software package. For ROZ200 we have 12 files, also with reverted scan on 90 deg.
****) Scan with VueScan and the new software package ROZ050—5 files.

4. WFPDB experience and results. The plate digitization done by the WFPDB team (the results are summarized in Table 4) includes plate images with optimal low- and high-resolution scans. The plate previews done at low resolution in JPEG format aim for quick plate visualization, as well as storing the observer's marks as an important part of the plate archive. They are a part of the database and can be accessed online. The plate images with high resolution are made in FITS format as a standard requirement. The high-resolution scans as a rule are accessible upon request. For bad quality plates only previews have been made.

The standards and metadata for digitized photographic plates are developed jointly with the team of the German Astrophysical Virtual Observatory in Potsdam [20]. The search interface gives information on the plate identifiers, coordinates, date, file type (compressed JPEG, TIFF, FITS), header of the FITS file, file size, and the scan.

The WFPDB plate digitization includes estimation of the quality of the digitization data and the respective decision on how to digitize the plate, as well as linking the scanned plate images to WFPDB for online access. A parallel process is the digitization of the related logbooks and observer's notes for the establishment of a link between the needed plate in WFPDB to the page in the logbook describing this plate through the methods and technologies for logbook data extraction.

The application of wavelet-based approaches to more effective compression of the huge volume of output scanned plate data [21] is also intended for preservation of digital content.

In the WFPDB we adopted preparation of digital archives of selected plates obtained in the frames of a given observing programme [22] in order to enable plate re-use as soon as possible. We have experience in the preparation of digitized archives of selected plates containing images of the Pleiades stellar cluster [23], minor planets and comets, supernovae [24], flare stars in stellar clusters and associations, variable stars which need larger statistical basis, Carte du Ciel plates [25].

For some of the digitised plates the Information Bulletin on Variable Stars (IBVS) is interlinked with the WFPDB [26], connecting the plates with images of discovered flare stars with the respective IBVS publications.

5. Conclusions. The astronomical photographic plates stored in observatories or other astronomical institutions contain valuable information on the past of observed astronomical objects. The plates are typical examples of scientific heritage, which has to be preserved and used for future investigations, especially in time-domain astronomy. The digitization of plates does not only preserve them, but also enables quick access to the image information. There is no universal procedure for scanning the plates, but an optimal one can be chosen for a given instrument (telescope).

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Received October 31, 2011
Final Accepted March 15, 2012