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Progress of the Chinese Plate-Digitizing Project

INVITED TALK

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Abstract. About 30,000 astronomical photographic plates were digitised between 2012–2017 with a special digitising machine that has high precision in both astrometry and photometry. All the images from the plates, together with plate information and measured coordinates of all the objects on the plates, have been stored in the Chinese Virtual Observatory.

Keywords. History and philosophy of astronomy, instrumentation: detectors, methods: data analysis, laboratory, techniques: image processing, astronomical data bases: miscellaneous

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1. Introduction

In 2011 the Project, ‘Digitizing all Chinese astronomical photographic plates (2012–2017)’, proposed by Shanghai Astronomical Observatory (SHAO) and the National Astronomical Observatories (NAOC) of the Chinese Academy of Sciences, was approved by the Chinese Ministry of Science and Technology. Between June 2012 and June 2017 four main tasks of the project were completed: (a) to build a plate archive and bring to it China’s entire collection of astronomical photographic plates, (b) to construct a dataset containing information about each plate, (c) to clean and digitise all the plates, and (d) to enter all the data into the Chinese Virtual Observatory.

The first Chinese astronomical plate was taken in 1901 with the 40-cm refractor of Sheshan Observatory (now under ownership of SHAO). From 1901–1998 about 30,000 plates were taken by more than 10 telescopes at SHAO, NAOC, Purple Mountain Observatory and elsewhere. The plates show many kinds of objects: asteroids, comets, binaries, variable stars, flare stars, new stars, supernovæ, radio stars, clusters, galaxies, and so on. Table 1 gives the statistics of the plates, including the originating observatory, telescope, and observing dates. Fig. 1 illustrates the time-span of the plates. Their dates extend from 1901 to 1999 – very nearly 100 years.

1.1. *Plate Archive*

Efficient preservation of the plates requires near-constant temperature and humidity. The special archive that was built has two machines to maintain temperature and humidity of the environment at 25°C and 50% RH, respectively, with only very small fluctuations. A monitoring system was developed to monitor the temperature and humidity of the archive; the temperature and humidity are also recorded manually. In order to keep the archive clean and orderly, new metal cabinets were obtained for storing plates; the latter were placed in different cabinets according to the originating observatory and the dates of the exposures.

Table 1. Statistic of Chinese Plates

Observatory	Instrument	Period
Shanghai	40-cm astrograph refractor 156-cm reflector	1901–1998 1988–1994
Beijing	40-cm astrograph refractor 60/90-cm Schmidt +object prism	1968–1990 1968–1990
Purple Mountain	15-cm refractor 40-cm astrograph refractor 60-cm reflector	1949–1986 1964–1986 1954–1965
Yunnan	100-cm reflector 40-cm solar spectrograph	1979–1985 1976–1997
Qingdao	32-cm refractor 15-cm astrograph (Xi-Sha Island for Halley's Comet)	1960–1997 1986

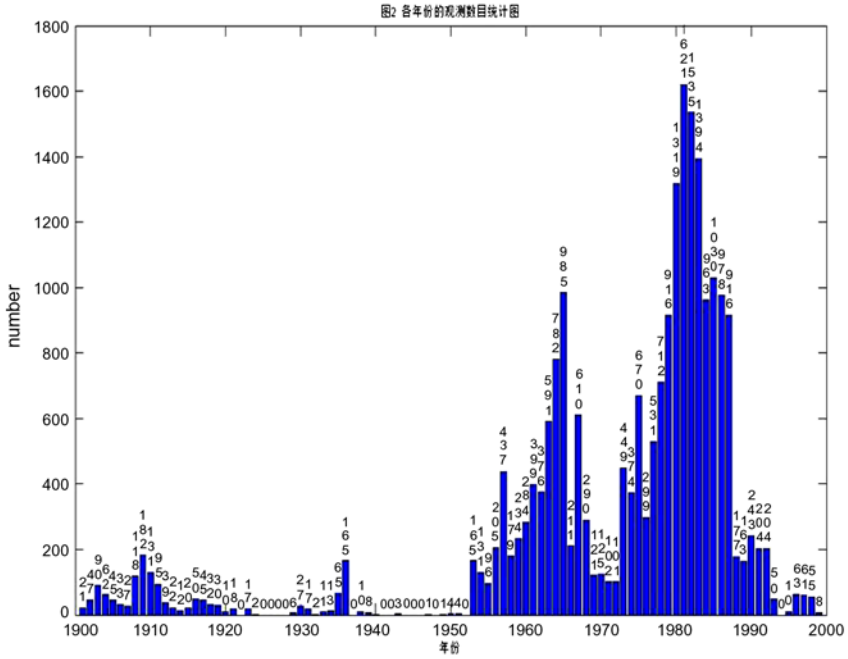

Figure 1. Time-span of Chinese Plates

1.2. *Information Dataset*

In order to be able to search the observational data conveniently, we extracted information about the plates manually from their envelopes, and built it into a dataset following the format of the *Wide-Field Plate DataBase* (`www.wfpdb.org`).

1.3. *Chinese Virtual Observatory*

To make the results of digitising the plates easy to use, the plate information dataset (Table 1), the images of plate envelopes, the original digitised images of all the plates and the measured coordinates (X, Y, I) of each object on all of the plates were entered into the Chinese Virtual Observatory. Those data will be accessible there by June 2018.

Table 2. Basic parameters of the machine

Item	**Value**
Astrometry	$<1\mu$ m/30cm
Photometry	<0.02 mag
Optical density	4.0
Scanning time	<10 minutes
Resolution	>2000 dpi
Optical distortion	<0.0001
Scanning area	>30 cm *30 cm

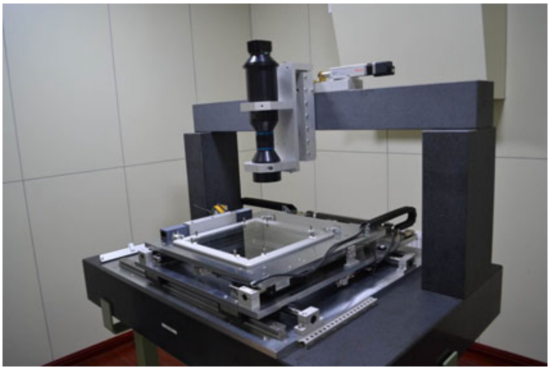

Figure 2. The SHAO digitiser

2. Fast Digitising Machine

In order to digitise the plates with high precision and accuracy, a fast, high-precision digitising machine was developed jointly by SHAO and Nishimura (a Japanese company) between 2012–2013. In 2014 January the machine was installed in the Sheshan plate archive (see Fig. 2). It took about two years to debug the machine before it could digitise plates reliably.

The basic parameters of the machine are shown in Table 2. It uses a linear scanning mode. It contains a moveable X–Y platform with a linear magnetic levitation motor, a double-sided telecentric lens, a linear array camera with a Complementary Metal Oxide Semiconductor(CMOS) detector having 4096 pixels that measure $10\,\mu$m × $10\,\mu$m per pixel, an LED light system, and a complete scanning control software system. The X–Y platform is mounted on a marble stage which in turn is mounted on an independent base that is connected to the bedrock of the mountain. The telecentric lens and camera are mounted on a guide rail which is vertical to the X–Y platform and acts as a Z-axis for focussing. The direction of the linear scanning is in Y; X is orthogonal to Y. In order to avoid vibration from the environment, the whole system is installed in the inner room of the plate library. To achieve high positional precision, each axis has a laser positioning system. To avoid air turbulence caused by operators or by the computer, a plastic shroud was built around the instrument. To avoid dust carried in by operators, and also to eliminate mould, all operators wear special clothes, a mask and goggles when digitising plates. Fig. 3 shows a sample image obtained by digitising two plates of Halley's comet with our machine. One plate was taken in 1910, the other in 1986.

Table 3. Comparison of positional repeatability for different machines.

Machine	**Detector direction repeatability (μm)**	**Line Scanning direction repeatability (μm)**
Epson V750	0.3	2.4
Epson 10000XL	0.4	3.4
SHAO machine	0.2	0.2

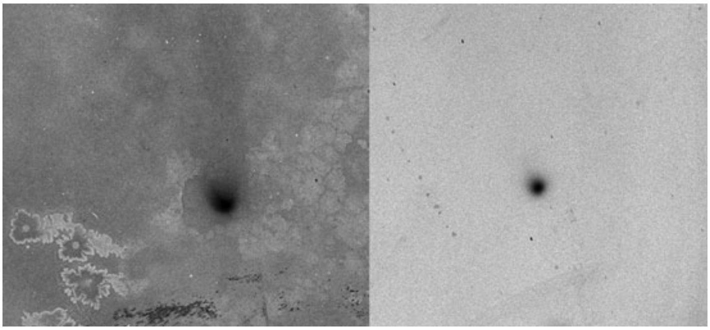

Figure 3. Digital images of two exposures of Halley's comet, *left:* taken in 1910, *right:* taken in 1986.

3. Performance Test Results

A series of tests was carried out to determine the precision of the machine and to ensure that it met the specified requirements. Detailed results of the test have been published by Yu *et al.* (2017); they are summarised below.

3.1. *Comparisons with Epson commercial scanners*

The output from our machine was compared with two commercial Epson machines: Epson V750 pro, and Epson 10000XL. One specification was positional repeatability. By scanning the same plate 10 times with each machine, we determined the positional repeatability of each machine, as shown in Table 3. *Repeatability* is calculated as the standard deviation of residuals of the coordinates of star images common to each plate. Our machine clearly performed better in each direction. *Systematic errors* in the scanning direction were also measured. Fig. 4 illustrates the distribution of standard deviations of stellar positions in the X direction along the scanning (Y) direction. The two commercial scanners have systematic errors amounting to nearly 20 μm, while those of the SHAO machine are much less. *Uniformity of illumination* was tested by operating the scanner without a plate. The uniformity of the SHAO machine proved to be good to 0.15%, compared to 2.2% for the Epson V750 and 3.7% for the Epson 10000XL (see Fig. 5).

3.2. *Digitising repeatability*

We have already described the results of testing the repeatability of the machine, and contrasting it with that of commercial ones. We also checked the repeatability by scanning a 50 × 50-mm calibration plate that bore standard dots having a high signal-to noise ratio. The calibration plate and a 300 × 300-mm astronomical plate were scanned and measured 5 times over. The standard deviations of the residuals of the image coordinates

Table 4. Test Results of Digitising Repeatability.

Object	**Measuring range (mm)**	$\bar{\sigma}_x$ **(μm)**	$\bar{\sigma}_y$ **(μm)**	$\bar{\sigma}_m$ **(mag)**	**Number of stars**
Calibration plate	50×50	0.024	0.028	0.0001	40,359
Astronomical plate	288×288	0.175	0.169	0.01	3501

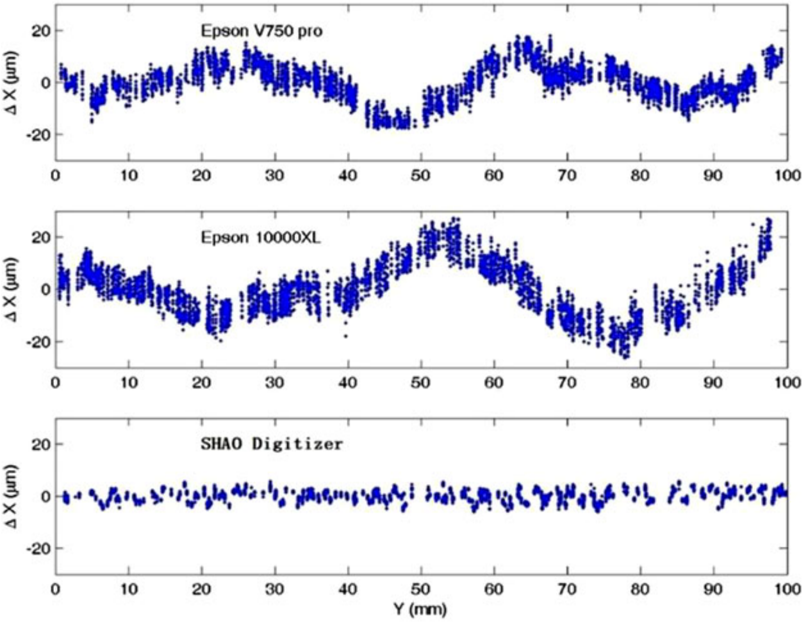

Figure 4. Comparing systematic errors in the scanning direction for different machines.

and the grey counts of the standard dots and of the stars are listed in Table 4. The root mean square (rms) of the positional repetition was 0.17 μm, and that of the brightness determinations was 0.01 mag.

3.3. *Systematic factors affecting digitised positions*

Manufacturing errors of the component parts, along with errors that occurred during installation, may also introduce systematic factors affecting the machine's positional performance. Those include lens distortion, optical resolution, non-linearity of rails and motors, deviation of the image mosaic, and non-orthogonality between the scanning direction and the CMOS array direction. However, each of those factors could be evaluated and calibrated. Fig. 6 shows the distribution of residuals in the direction of the linear CMOS array which could reflect distortion in the lens, and how it was corrected after calibration. More details of these tests can be found in (Yu *et al.* 2017).

3.4. *Comprehensive test of digitiser*

The calibration plate is much smaller than the whole scanning area of the machine, so we used the 300 mm × 300 mm astronomical plate mentioned above to carry out a comprehensive test of the precision over the entire digitising area. To that end, we rotated the plate through 0°, 90° and 180° in turn, and scanned it repeatedly at each

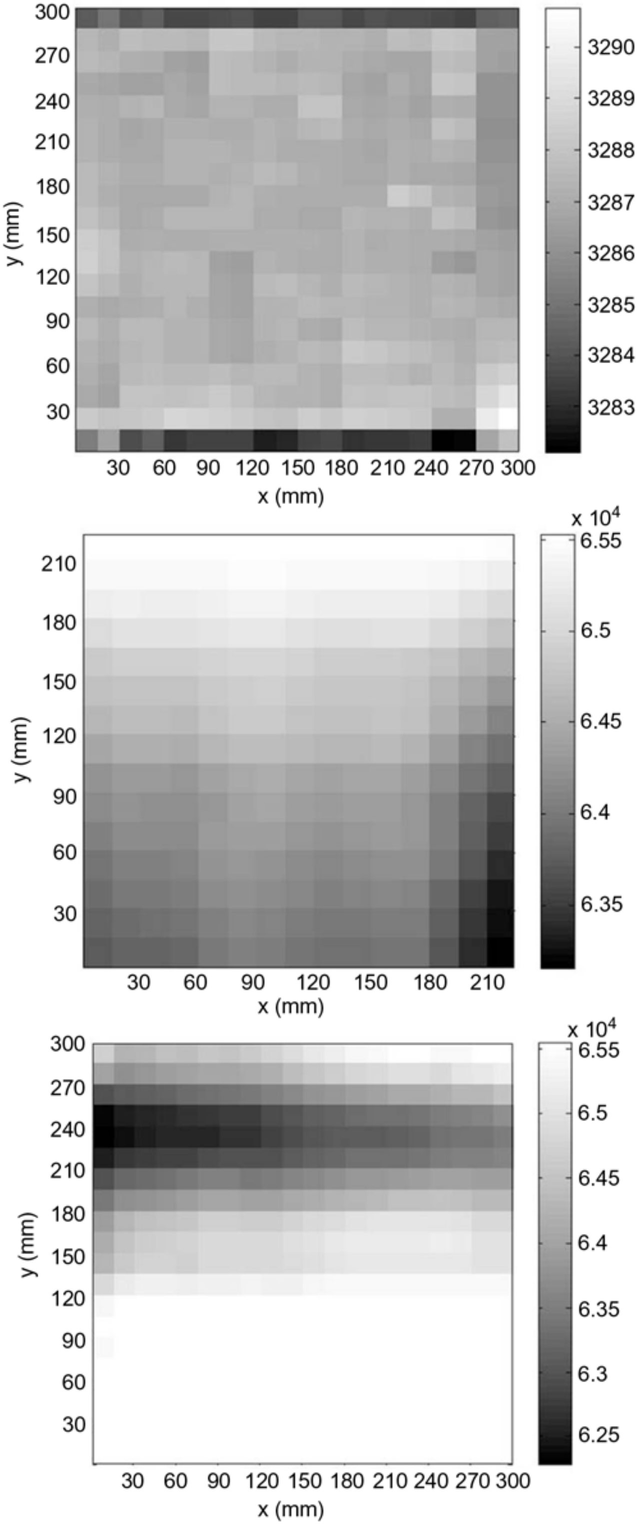

Figure 5. Testing uniformity of illumination. SHAO machine (top), Epson V750 (centre) and Epson 10000XL (bottom).

Table 5. Standard deviations derived from the 0° image compared to those from the 90° image, and similarly between the 0° image and the 180° image.

	σ(μm)	
No	**0°–90°**	**0°–180°**
1	0.79	0.87
2	0.76	0.84
3	0.75	0.86
4	0.75	0.87
5	0.79	0.84
6	0.79	0.88

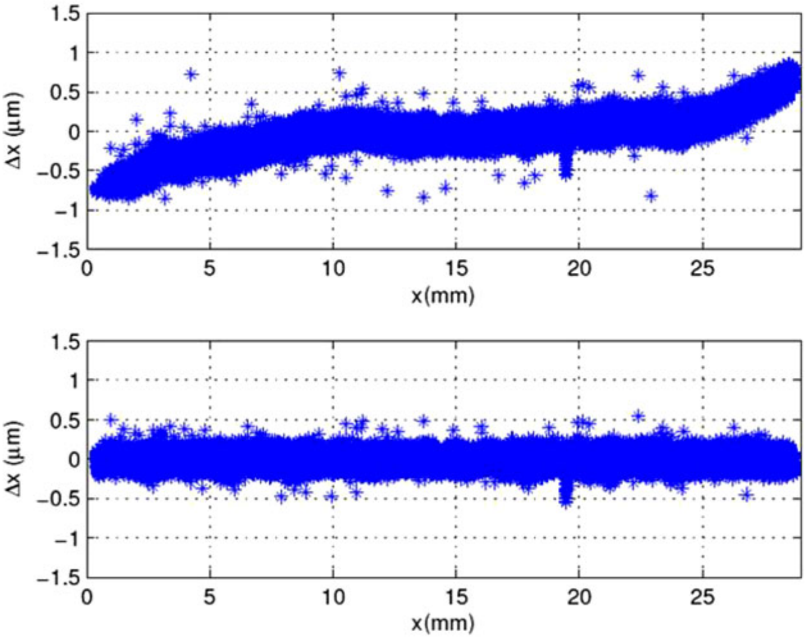

Figure 6. Distribution of residuals in the direction of the linear CMOS array. *Upper:* before calibration; *lower:* after calibration.

orientation. We then overlaid the stellar images as measured at the different orientations and calculated the distribution of the residuals between their positions on the 0° image and the 90° image, and similarly between the 0° image and the 180° image. Table 5 lists the results of this test. It can be seen that the standard deviation is smaller than 0.9 μm. The standard deviation actually contains the digitising error and a centroiding error, so the error of our scanner is smaller than 0.7 μm.

4. Future Plans

So far we have only created digital images from the plates. However, the task does not end there; it is as important to extract scientific quantities from the digital images. We have calculated the (X,Y) coordinates of each celestial object on the plates, and determined the brightness (grey count, I). We plan next to create a catalogue for each plate that converts those (X, Y, I) to (α, δ, magnitude), based on Gaia DR2. At the same time, we hope to carry out research on any long-term phenomena which our digitised data reveal, recalling that the time-span of the material is nearly a century and is undoubtedly advantageous for studies of long-term phenomena.

The project has provided us with considerable practical experience in digitising plates. We therefore have plans to create an international laboratory for plate digitising and open it to the entire world. Under the auspices of the ‘Belt and Road’ framework initiated by President Xi of the People’s Republic of China, our hope is to cooperate with observatories world-wide in matters of digitising astronomical plates.

References

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