The level of accuracy for digitizers dedicated to astrometry

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Abstract

We discuss different parts of the digitization process and their influence on the final measurement for astrometry. The goal is to define what could be the adapted digitizer components providing the required astrometric accuracy. We base our discussion on the use of the new generation DAMIAN scanner with USNO photographic plates. Thus we evaluate intrumental parameters and their influence such as the stability and the position repeatability, with optical parameters such as the camera optical distortion and repeatability.

I. Introduction

The study of the dynamics of the natural planetary satellite systems needs astrometric observations. And the interval of time must be as long as possible in order to quantify long period terms and to analyse the evolution of the motion.

A new reduction of good photographic plates is a solution but needs a specific instrumentation to provide the best (?) accuracy. Some questions : what are the main components of a digitizer ? what is the influence on the final measurements ? which accuracy could be obtained ?

We use the USNO photographic plates for example to discuss the machine parameters that achieve a final astrometric accuracy of 1.5 mas ($\simeq 0.075\ \mu m$).

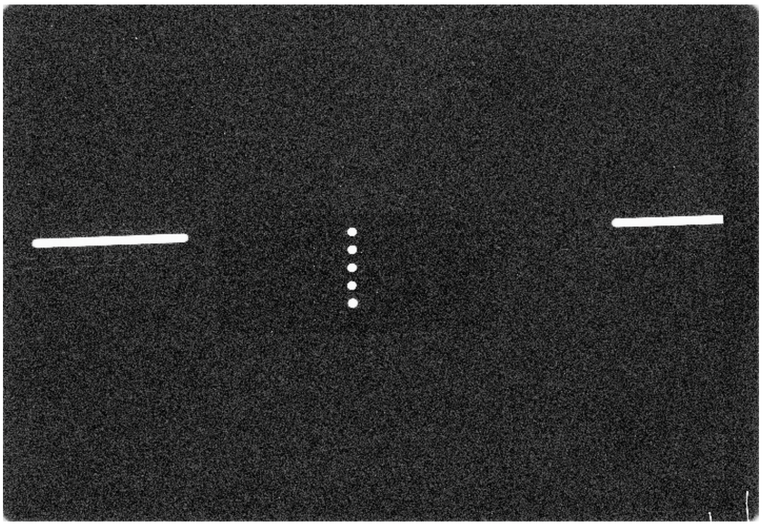

Fig. 1 – Digitization of the USNO plate n2114 (positive).

II. The digitization

We first compared some specifications of MAMA (Guibert et al., 1991), StarScan (Zacharias et al., 2008) and DAMIAN machines (Robert et al., 2011 ; Robert, 2011) in the case of the digitization of USNO photographic plates. It appears that the DAMIAN specifications are better than the StarScan reference digitizer.

	MAMA	StarScan	DAMIAN
Time	1 h	20 min	8 min
XY positioning	1 μm	0.1 μm	0.001 μm
XY repeatability	1.17 μm	0.50 μm	0.07 μm

Tab. 1 – Compared specifications of MAMA, StarScan and DAMIAN machines.

An easy way to discuss some machine components, with the DAMIAN scanner for example, is to consider two main parts : the mechanical part (XY-table) and the optical part (2D camera optical unit). Then the environment will contribute.
The XY-table main terms are :

1. the linear encoders (absolute/incremental), devices that read the table position
2. the positioning stability, that is the deviation of a fixed position, the error/difference between the real position and the measured position
3. the positioning repeatability, that is the measuring dispersion, the interval variation of several measurements

The optical unit main terms are :

1. the unit quality
2. the reading accuracy, including the optical distortion and the image correction for Dark, Flat and Offset

The environment main terms are :

1. the environment stability, including the influence of the temperature, the pressure and the relative humidity

We present a comparison between manufacturer (man.) and measured/estimated (mes.) DAMIAN specifications :

	DAMIAN (man.)	DAMIAN (mes.)
XY positioning	1 nm	1 nm
XY stability	$<$ 10 nm	3 nm
XY repeatability	$<$ 10 nm	3 nm
Optical accuracy	70 nm	70 nm
Global accuracy	$<$ 90 nm	77 nm

Tab. 2 – Manufacturer and measured/estimated specifications of DAMIAN digitizer.

The green 77 nm were determined with several measurements of USNO cluster plates, and because the optical unit accuracy is of the same order, red data are estimations. But we can see that the DAMIAN scanner already reaches the expected 1.5 mas astrometric accuracy. The question is : do we need such a performing mechanical part for which the cost is ten times higher than the cost of a good optical unit ?

	DAMIAN (mes.)	Astrometric machine
XY positioning	1 nm	10 nm
XY stability	3 nm	30 nm
XY repeatability	3 nm	30 nm
Optical accuracy	70 nm	30 nm
Global accuracy	77 nm $\simeq$ 1.5 mas	100 nm $\simeq$ 2 mas

Tab. 3 – Estimated specifications of DAMIAN digitizer and an astrometric machine.

It is possible to consider a common machine that reaches 2 mas astrometric accuracy :

1. increasing the positioning reading, stability and repeatability values permits to build a fast digitizer
2. improving the optical unit (pixel size, dynamics, resolution) permits to digitize more extended areas in the same time and thus to reduce the scan delay
3. performing several digitizations permits to decrease the global accuracy by a $1/\sqrt{n}$ factor

The question is : do the machine differences decrease the cost significantly ? A small part of this economy should be used to improve the optical unit.
Note that this kind of machine is very specific so that there are very few manufacturers able to build such engines. In that sense, it would probably be too complicated (expensive ?) to fundamentally change the components.

We also know that the environment in which the machine is placed can influence the optical unit response, the temperature in particular. In the case of the DAMIAN digitizer, the scanner is placed in an air-conditioned clean room at a temperature of 20°C±0.05°C. Ensuring such a stability represents a non-neglictible cost in the machine maintenance.

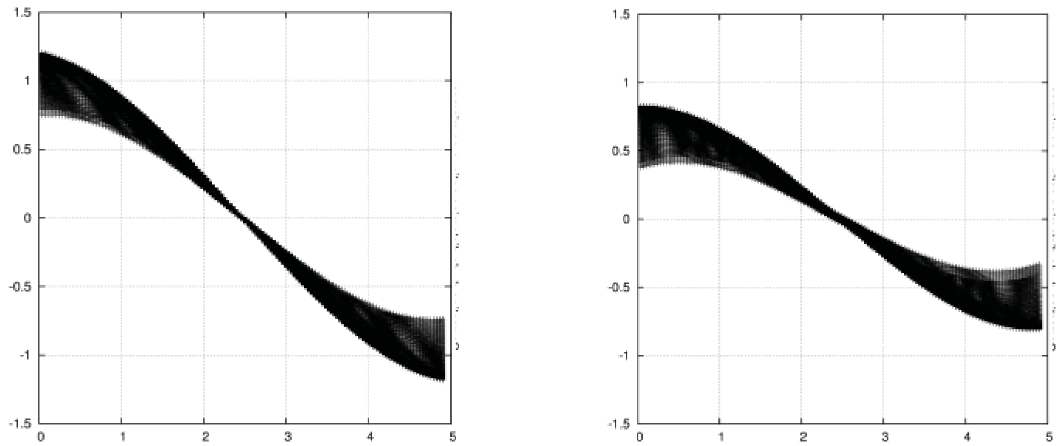

Fig. 2 – x (left) and y (right) subimage distortion corrections in μm related to initial x and y position in mm.

The common camera distortion correction is up to 1.26 μm on the x-axis and 0.78 μm on the y-axis ; a Δt variation of 1°C introduces a Δc distortion correction up to 0.2 μm ($\simeq$ 4 mas). We can deduce that the machine should be placed in an air-conditioned clear room with at least fixed temperature with ±0.25°C.

III. Conclusion

The DAMIAN digitizer is the best current machine dedicated to digitization. It already reaches an accuracy of 1.5 mas but its mechanical part is sized to provide better results.

Considering a new machine is interesting. The best way would be to balance the mechanical and optical precisions to reach an accuracy of 1.5 mas. It is possible to custom catalog products but the economy will not probably be really significant ?

It will be important to improve the next steps of the process (image analysis, use of star catalogs, ...) not to decrease the accuracy at this point.

References

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