THE NAROO DIGITIZATION CENTER

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Abstract. The New Astrometric Reduction of Old Observations NAROO center is built at Paris Observatory, Meudon, and is dedicated to the measurement of astro-photographic plates and the analysis of old observations. The NAROO digitizer consists of a granite based Newport-Microcontrol open frame air-bearing XY positioning table, a scientific sCMOS camera, and a telecentric optical system. The plate holder assembly is suited for mounting glass plates up to 350-mm square. The machine positioning stability is better than 15 nm, its repeatability is better than 40 nm. With real photographic plate data, we are able to produce measurements with an accuracy better than 65 nm.

The renewed interest about photographic plates concerns the expansion of the database of transient objects evolving in time, since digitization now makes it possible to measure images with a high level of accuracy and to identify all the available objects. The information extracted from such materials can be of an astrometric, photometric, and spectroscopic nature, when not purely imaging, with consequences in planetology, near-Earth asteroid risk assessment, astrophysical phenomena, and general relativity, to mention but a few. Through our scientific program in the Gaia era, we detail examples of current and upcoming uses for the community. We invite researchers to use our facilities and digitize their collection by answering our call for proposals.

We will present first results of mass digitizations and scientific application to the Galilean system using Gaia-eDR3 reference star catalog, and first results of NEA precoveries. We will also give details for the researchers to use our facilities and digitize their collection by answering our Call for Proposals.

Keywords: instrumentation: high angular resolution, techniques: image processing, digitization, photograhic plate

1 Introduction

The renewed interest about photographic plates concerns the expansion of the database of transient objects evolving in time, since digitization now makes it possible to measure images with a high level of accuracy and to identify all the available objects. The information extracted from such materials can be of an astrometric, photometric, and spectroscopic nature, when not purely imaging, with consequences in planetology, near-Earth asteroid risk assessment, astrophysical phenomena, and general relativity, to mention but a few.

Studying the dynamics of Solar System bodies, in particular, requires astrometric observations sampled over a long time span to quantify the long period terms which may help to analyze the evolution of the motion. Searching for old data is obviously useful for this purpose, and since we have demonstrated that a precise digitization and a new astrometric reduction of old photographic plates could provide very accurate positions (Robert et al. 2011, 2015, 2016), researchers involved in various scientific topics began to (re-)consider such materials. As a consequence, the Paris Observatory decided to acquire such an instrument and to build a scientific community for its exploitation, creating the New Astrometric Reduction of Old Observations NAROO program.

2 The NAROO center

The NAROO center is a unique place dedicated to the sub-micrometric analysis of old astro-photographic plates, fort scientific purposes only.

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Fig. 1. Logo of the NAROO center.

2.1 *Hardware*

Figure 2 shows the NAROO digitizer as of April 2020. The machine consists of a granite-based Newport-Microcontrol open-frame and air-bearing XY positioning table, with a plate holder assembly suited for mounting glass plates up to 350 mm squared. The NAROO machine is able to process almost all known transparent photographic plate materials automatically.

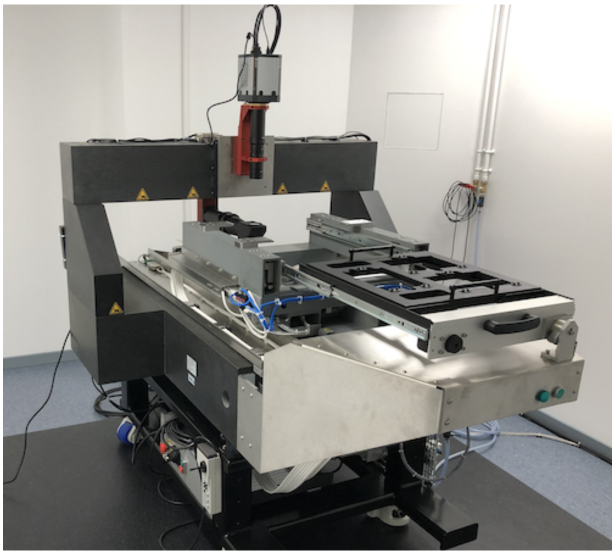

Fig. 2. NAROO machine at the Paris Observatory, Meudon.

The granite base measures 1.3 m × 1.3 m × 0.2 m. It is mounted on dynamic feet to compensate for the building and environment vibrations. The position of the XY-table is read by Heidenhain encoders with an accuracy better than 2 nm. The linearity and orthogonality of XY-axes were calibrated by Newport-Microcontrol using a laser interferometer. The local XY-table positioning was measured by the manufacturer with a capacitance up to 7 nm. The repeatability, how closely the XY-table can return to an initial position following movement over the entire XY-axes, was also measured by the manufacturer with a capacitance up to 40 nm. In order to reach and maintain a high geometric and radiometric accuracy, the digitizer is placed in an overpressure, air-conditioned, ISO-5 clean room, at a temperature of 20°C ± 0.1°C and a relative humidity of 50% RH ± 5% RH.

The optical unit consists of an Andor Neo sCMOS Camera, mounted on a VST VS-TCM-130/S telecentric 1:1 objective. This system is attached to the Z-axis above the XY-table. The photographic plates are illuminated from below with light emitting diodes (LEDs), controlled by a high-precision DC power supply. We paid particular attention to the complete optical system which was specifically designed by the instrumentation pole of the Paris Observatory to evenly illuminate the plate and avoid vignetting. The 2D sCMOS Camera generates images with 2560 by 2160 pixels of 6.5 µm by 6.5 µm. The maximum dynamic range is 30,000:1. Each frame results in a 16-bit FITS file with 11 MB disk space. For instance, the digitization of a classical 5 by 7 inch Kodak plate requires about 1.2 GB of disk space, while that of a 350 mm squared Schmidt plate is up to 5.9 GB.

2.2 Digitization process

Most of the NAROO functions are computer controlled. Depending on their size, one or several photographic plates are put inside a plate holder that is mounted on the XY-table. At the beginning of each digitization process, the supports are automatically put into focus, with the emulsion facing up, by clamping the plate holder upward against the counterpressure rack. The illumination is set to 3/4 of the saturation on the plate's sky background by adjusting the DC power supply unit to the LED. The plate is automatically digitized in step-and-stare mode with steps corresponding to user-defined moves in the X and Y directions. The local XY-table position is read by the Heidenhain encoders and inserted into the image header. After the plate digitization is complete, the XY-table automatically returns to its home position, and the plate holder is unclamped in anticipation of a new cycle. As a final product of digitization, an overall mosaic FITS image of the whole photographic plate is generated from the individual images with or without overlapping.

The time needed to digitize a single classical 5 by 7 inches Kodak plate with about of 120 individual images is 5 min, taking into account the overall movement from the XY-table home position and return. That of a complete Schmidt plate with about 550 individual images is 22 minutes.

3 Scientific program - First results

The information extracted from photographic plates are of an astrometric, photometric, and spectroscopic nature, when not purely imaging. Robert et al. (2021) provided details of current and upcoming scientific programs, in which the NAROO center is involved, as examples for the community and to possible interactions. Anyway, results of the first mass digitizations will be published soon.

3.1 USNO Galilean plates

A set of about 550 plates of the United States Naval Observatory USNO was digitized with the NAROO machine. These plates are observations of the Jovian system realized by Dan Pascu between 1967 and 1998 (Pascu 1994). They result in about of 2650 original observations. One should note that we previously measured these observations with the DAMIAN machine in 2010 (Robert et al. 2011), and we provided equatorial positions for the Galilean satellites using UCAC2 reference stars (Zacharias et al. 2004). Nevertheless, the complete results and positions were never published.

This previous work allowed us to make various comparisons with the new NAROO measurements, 10 years later. We compared both DAMIAN and NAROO measurements, we compared both UCAC2 and Gaia-eDR3 (Arénou 2020) star catalogs for the references, and obviously different planetary and satellite ephemerides. First, our results show that the NAROO machine provides the best digitizing accuracy. In fact, the satellites residuals over 30 years show that the DAMIAN machine was affected by a mean random error of 4.4 mas, that is to say about of 210 nm. Then, combining the NAROO digitizations and Gaia stars will provide the best accuracy for old observations, since the mean residuals are decreased by about of 10 mas, that is to say about of 30 km, by comparison with the first measurements.

The intersatellite positions of the USNO Galilean observations, over 30 years, are about of 30 mas versus 100 mas with the very first measurements by Dan Pascu. The equatorial positions of the USNO Galilean observations, over 30 years, are about of 55 mas, that is to say 165 km.

3.2 OCA asteroid precoveries

A PhD was started at the NAROO center in 2020 because we thought that dynamics of small Solar System bodies could benefit from long-term astrometry provided by the NAROO machine. In particular, we thought that photographic plates realized at the Observatoire de la Côte d'Azur OCA could be a source of old observations of Potentially Hazardous Asteroids PHA of the XXth century since the collection was exactly realized for the detection of new asteroids. They could have been observed even if it was not the purpose of the original observation. And we found several precoveries of PHAs in the collection, and the analysis is still in progress. As an example, Figure 3 shows the precovery in 1982 of asteroid 2006 SU49. The precovery is 24 years before the official discovery.

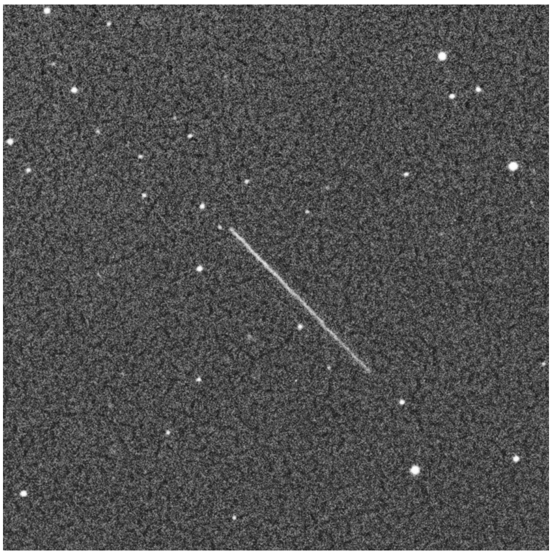

Fig. 3. Precovery in 1982 of asteroid 2006 SU49.

4 Call for Proposals

The value of a new analysis of old photographic plates has been demonstrated, and the community is beginning to worry about the use and preservation of such materials for science. As recommended by the resolution B3 of the XXX IAU General Assembly in 2018, the preservation, digitization, and scientific exploration of the plates must be realized. Plate collections of the Paris Observatory and other French and international institutions are being digitized to provide data spanning more than one century for our works. Corresponding results will be presented in upcoming papers. Digitized raw data will also be available for the community.

The NAROO machine is available for researchers to digitize their own collections for scientific purposes, since digitization time is reserved for external users. A call for proposals is being issued every six months via our project website `https://omekas.obspm.fr/s/naroo-project/`.

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