

NEO DETECTION USING IMAGE STACKING METHOD IMPLEMENTED IN CELESTIAL COORDINATES

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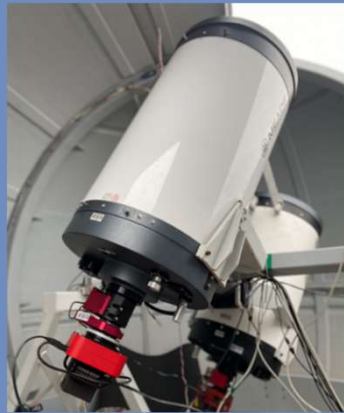
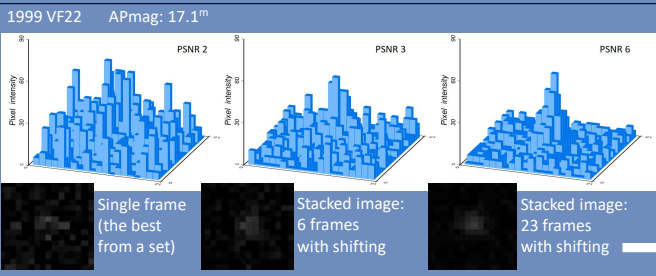
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Introduction

In this study, we propose the method of CCD frame stacking, which is implemented in celestial (equatorial) coordinate system. This method allows to prolong the "effective exposure time" of near-Earth objects (NEOs) increasing the efficiency of capturing faint objects. Additionally, it can be realized using CCD frames obtained via several optical systems simultaneously or at different epochs.

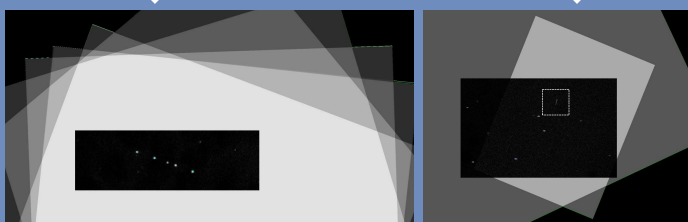
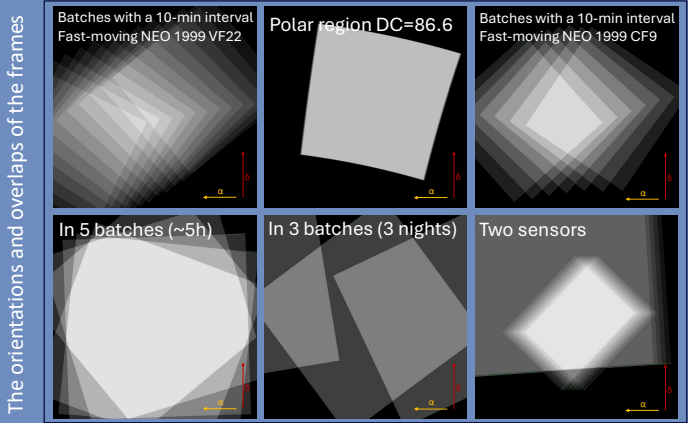
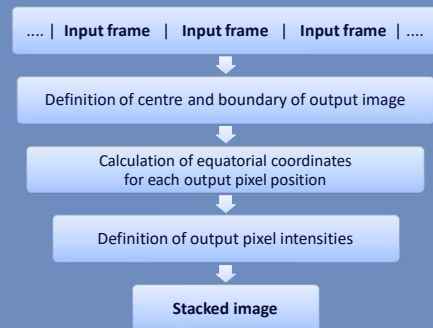
Frame stacking method

Stacking of CCD frames is usually done by comparing patterns on frames or directly overlying images and requires frames obtained via the same telescopes and in similar circumstances. The proposed use of equatorial coordinates allows to stack frames, which have different epochs, scales, distortions and framing. This approach requires an astrometric solution for all involved frames, i.e., transformation from image (pixel) coordinates to equatorial coordinates. Stacked frame is generated in a rectangular coordinate system, with coordinates of right ascension and declination. Thus, implementation of this approach ensures the possibility to combine frames obtained at different epochs and using different optical systems. It allows to increase the brightness of NEOs also in situations where circumstances such as weather, astroclimate, hardware capabilities, specific locations, force to put up with short exposures, small sensors and bright sky background.

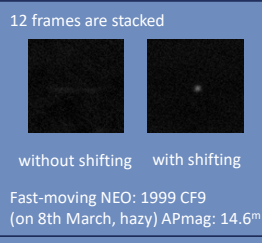


Instrumentation

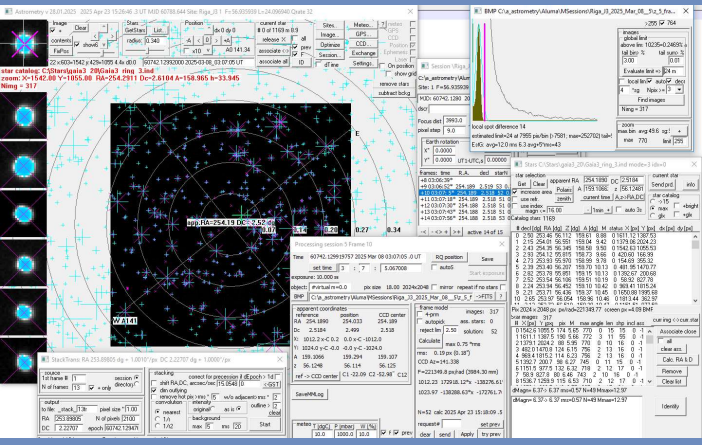
The OTS (optical tracking system) includes twin receiving OTAs, which are symmetrically mounted on an Alt-Alt mount. This type of the mount ensures continuous object tracking in zenith region unlike Alt-Az mounts. Each OTA has an ACF 16-inch (about 0.41 m) F/10 optic (focal length: 4 m). The system is equipped with two CCD matrices: 16.8 Mpix (4096x4096) and 8.3 Mpix (3326x2504). A more advanced model ensures a FOV of 0.5° x 0.5° with a minimum pixel size of 0.46 arcseconds.



Stack of 25 5-s frames with moving asteroid during a 5-h period. The proposed method increases the brightness of the asteroid within one session (batch) with a set of consequent images with short exposure and provides the trajectory of its movement during the entire period. Stack of 2 frames obtained via two CCD cameras simultaneously. This proves that the use of equatorial coordinates allows the processing and stacking of frames obtained using different sensors.



The control software is developed using MS VisualStudio C++ and C#. The astrometry module supports image acquisition and near-real-time analysis. It controls the CCD camera settings, contrast enhancement and object image recognition, ensures reference star selection and identification, and determines the object coordinates. The module includes the vector astrometry software package NOVAS for calculating the apparent places of stars. A subset of the Gaia star catalog (data release EDR3), consisting of astrometry and star magnitude data for stars brighter than 21st, is used.



Conclusions

- The new method for astronomical imaging – the method of CCD frame stacking in equatorial coordinates, is presented. It has several advantages in detecting NEOs and can be adapted for various observation strategies.
- The main strengths are the ability to increase the brightness of faint NEOs using also small sensors and the ability to combine frames obtained via multiple optical systems simultaneously, ensuring the detection of small and fast-moving NEOs.
- More results obtained using different optical systems and their combinations are needed to fully evaluate the effectiveness of the proposed method.



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