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NOAP PLANNER 0.6.5 — FEATURES OF NEO OBSERVATIONS PLANNING WITH ONE BUTTON

Last year, a package of Python scripts NOAP (NEO Observation Analyzer and Planner) was presented in this journal. It is designed to plan NEO observations and analyze existing observations automatically. Over the past year, this package has undergone significant changes, in particular, the planning pipeline has been updated. The main goal of the update was to simplify and automate the observation planning process as much as possible, as well as to increase the quality of the object selection for observation. This article highlights the main changes made to the Planner pipeline and discusses the features of automated planning of NEO observations for small-aperture telescopes. An algorithm has been developed for the automated processing of data from the NEOCP Minor Planet Center website, which allows for detecting new objects that require confirmation much faster. Additionally, an adaptive NEO filtering algorithm has been developed, considering the speed of NEO's apparent motion and its expected brightness. This makes it possible to improve the magnitude limit for slower NEOs and to discard objects that cannot be observed with a given telescope due to the "velocity — brightness" correlation.

The article also discusses a new feature of automated ephemeris calculation for fast objects, which allows us to avoid the loss of observations due to the object moving too fast across the telescope's field of view. Thanks to this approach, the possibility of error occurring during planning was minimized, and this procedure became available for simultaneous observation planning for several observatories.

The implementation of new algorithms allowed for a significant increase in the efficiency of observations, especially for objects with low brightness. The study provides examples of the new planner application for the L18 station and demonstrates statistical data confirming the improvement in the accuracy and quality of observations.

Keywords: *NEO, optical observations.*

INTRODUCTION

The first version of the NOAP (NEO Observations Analyzer and Planner) package of Python scripts was described in detail in [3].

Structurally, NOAP consists of two script pipelines: Planner and Analyzer. The first of them is intended for planning observations of near-Earth objects (NEO) at various observatories, and the second is for analyzing the received observations based on the NEODyS-2 database [6]. According to the results of using NOAP [3], several directions for its improvement were highlighted.

For Planner pipeline:

• batch calculation of ephemeris and observation plans for several observatories;

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• change of the algorithm for obtaining data from the NEOCP [9] webpage for more prompt detection of the appearance of new objects that require confirmation;

• an adaptive algorithm for filtering NEOs that can be observed with the given telescope, taking into account both the velocity of their visible movement and the predicted brightness. This will increase the limiting magnitude for slower NEOs, increase the time of NEOs in sight, and reject NEOs that cannot be observed with the given telescope according to the "brightness — velocity" ratio;

• the introduction of a graphical user interface;

• integration of the "Planner" pipeline with the "Analyzer" pipeline for priority calculation.

For the "Analyzer" pipeline:

• compatible statistics calculation for several observatories;

• quality assessment of NEOCP object observations;

• validation of the observations before they are sent to the MPC;

• the optimization of additional calculations, especially those associated with data modification.

In this paper, we will show how exactly the changes were made to the Planner pipeline alone, bringing it to version 0.6.5.

1. CHANGES MADE TO THE PLANNER PIPELINE

Unfortunately, only the first and third points of improvement have been implemented, so far, but we

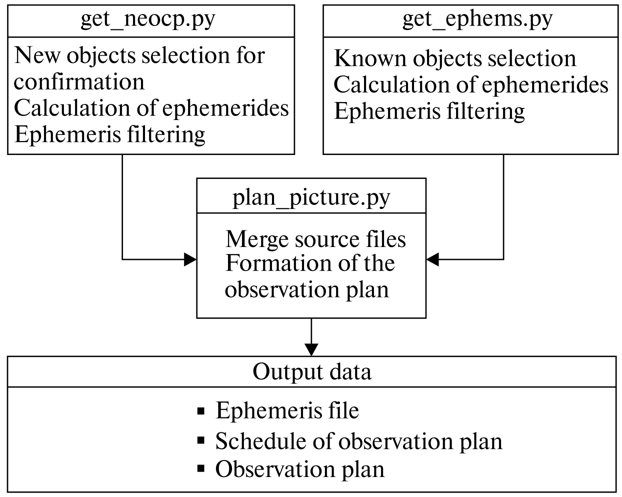

Figure 1. Structure of the previous version of the Planner pipeline [3]

consider them to be among the most important ones. Below we will dwell on each of them in detail.

1.1 Batch Calculation. The first versions of the pipeline required the sequential launch of three of its scripts (Fig. 1) to obtain the observation plan and ephemerides. The disadvantages of such a solution are insignificant when working with one observatory, but they can become a serious obstacle if it is necessary to plan observations for several observatories at once.

Therefore, changes were made to the pipeline operation scheme (Fig. 2). Now, all three "calculation" scripts are launched by an additional control script *main.py*, and calculations are performed for all ob-

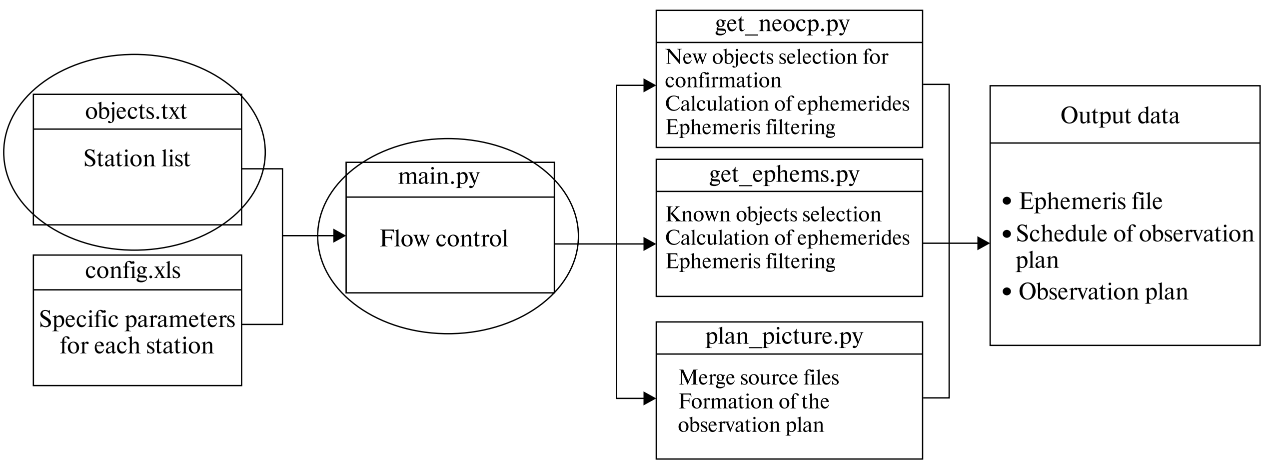

Figure 2. Structure of the current Planner pipeline's version. The ovals show new elements that provide "one-button" planning.

servatories specified in the *objects.txt* list. Thus, from now on, planning observations, even for several observatories, is done virtually "with one button".

1.2. Adaptive Algorithm for Filtering NEOs. The algorithm for selecting NEO for observation is as in [3], regardless of the influence of NEO's apparent motion speed on the ability of their observation. This influence is determined by the fact that the greater the speed of a NEO, the less "effective" its exposure is. Here, effective exposure is the maximum exposure value at which photons from the observed NEO fall on the same pixel of the optical sensor camera. It depends on the image scale and the velocity of the NEO's apparent motion. The calculation of effective exposure is shown in [3] as the calculation of exposure for observations. Thus, the fainter and faster the NEO is, the higher the probability that in sidereal tracking observing mode, during the effective exposure, the pixel will receive such a small amount of light from a given object that this may not occur when using the "shift-and-stack" technique (or "synthetic tracking"), see the example, [1, 7, 10—12]. In addition, faint and fast NEO may also require a number of frames that can't be obtained while the NEO is in the field of view of the observing telescope.

Thus, it can be stated that the limiting magnitude for a relatively slow NEO is significantly lower than for a fast one. An increase in the limiting magnitude will lead to the fact that a great number of faint objects that cannot be observed due to their high speed will be included in the NEO list for observation. So, there was a need for a highly advanced algorithm to assign NEOs that will be planned for observations. This algorithm has to reject objects considering the mutual influence of their apparent brightness and apparent motion speed on their visibility.

In order to balance the mutual influence of NEO speed and brightness on the ability of their observation, it is necessary to go to NEO filtering for approximate values of the "signal-to-noise" ratio (SNR) of their images that the given telescope can form during the effective exposure time.

To calculate SNR, we use the so-called "CCD Equation" [5]:

$$SNR = \frac{S}{\sqrt{S + n_{pix}(N_{sky} + N_{dark} + N_r^2)}}, \qquad (1)$$

where $S = f(m_{NEO}, t_{\exp}, tel)$ — signal from the NEO of interest, n_{pix} — the number of pixels that the NEO image takes up, $N_{sky} = f(m_b, t_{\exp}, tel)$ — noise from the sky background, $N_{dark} = f(t_{\exp}, cam)$ — camera's dark current noise, $N_r^2 = f(cam)$ — camera's readout noise, m_{NEO} — NEO's magnitude, $t_{\exp}$ — effective exposure calculated by [3], *tel* — telescope parameters (aperture size, obstruction, number of optical surfaces, scale), m_b — sky background level considering the influence of the atmosphere and the Moon, *cam* — camera parameters (dark current level, temperature, readout noise level, ADC bit depth, pixel full well).

The obtained SNR value is compared with the threshold, and if it appears to be less than the threshold, the NEO is removed from observations. More detailed information on the calculation of each component can be found in [5, 8]. The influence of the atmosphere and the Moon on the sky background level was determined according to [4].

1.3. A New Alternative to Calculate the Required Number of Frames. Since there is an estimation of the SNR predicted value of the NEO image in one frame (1), it is possible to calculate the number of frames that need to be obtained N_{frames}:

$$N_{frames} = N_{obs\_est} \cdot \left(\frac{SNR_{obs\_est}}{SNR} \right)^2, \qquad (2)$$

Where N_{obs_est} — minimum number of observations planned to obtain (usually 3 or 4), SNR_{obs_est} — needed SNR of NEO image for one observation.

1.4. «Adaptive» Ephemeris for the Observations of Fast NEOs. By default, the ephemeris is calculated so that the predicted position of the observed NEO is in the center of the frame. There is nothing special about this if the object is slow or the telescope field of view is large enough. But there exists a possibility when the field of view is relatively small, and the NEO has such a speed that will allow it to pass half of the field of view that remains to be covered faster than the camera takes a given number of frames. In this case, the shooting may turn out to be inconclusive because the number of frames in which the NEO is in the field of view may not be sufficient to obtain at least three required observations using the "shift-and-stack" technique. In order to consider such cases, it is suggested to calculate the "adaptive" ephemerides as follows.

1. For each line of the ephemeris, the path L that the given NEO will pass during the shooting is determined:

$$L = (Sky_{motion_{NEO}} / 60) \cdot t_{exp} \cdot N_{frames},$$

where $Sky_{motion_{NEO}}$ — NEO's apparent motion speed, arcsec/min; N_{frames} — the total number of frames need to be shoot.

2. The obtained value is compared with the minimum size of the field of view along one of the coordinates min (L_{RA}, L_{Dec}).

2.1 If $L \leq 0.4 \cdot \min(L_{RA}, L_{Dec})$, then nothing happens.

2.2 If $0.4 \cdot \min(L_{RA}, L_{Dec}) < L \leq 0.8 \cdot \min(L_{RA}, L_{Dec})$, then the telescope aiming point is shifted for $0.5L$ forward along the trajectory of NEO's motion.

2.3 If $0.8 \cdot \min(L_{RA}, L_{Dec}) < L$, then N_{obs_est} is reduced by 1 and N_{frames} are recalculated according to expression (2). After the reduction, L is calculated again. If condition 2.3 continues to be fulfilled, then the reduction of N_{obs_est} is repeated until the value reaches 3. If condition 2.3 continues to be satisfied, then this row is removed from the ephemerides' list.

1.5. Changes in the File Configuration. Due to the modifications made to the program, the configuration file has also been changed. Previously, it was a simple text file with separate subsections, but now it is a file in .xlsx format, consisting of three separate sheets.

The *Stations* sheet stores all the data on observatories for which observations can be planned, including the telescope's specifications required for the algorithm operation described in subsections 1.2—1.4. The *obs* sheet contains the constants required for the pipeline operation, including the ability to switch to manual mode for determining the interval to calculate the ephemeris. The *system* sheet contains the paths required for the correct operation of the pipeline.

2. RESULTS

First of all, we should mention increasing the pipeline's usability. This concerns the "one-button planning" approach itself. Now, with a correctly formed configuration file and no failures in the pipeline, the possibility of incorrect planning of observations due to the operator's fault is practically excluded, moreover, for any reasonable number of facilities (for the time being, the pipeline is successfully coping with the automatic planning of observations for five facilities at once: three real facilities with MPC codes L18, L99, M32 included in the National Space Facilities Control and Test Center of State Space Agency of Ukraine and two "experimental/virtual" facilities created for tests).

Secondly, there is an effect of reducing the dependence of the obtained observations' accuracy on the

Table 1. **Statistics of NEO observed by L18. The initial data from the NEODyS-2 site were obtained and processed with the Analyzer pipeline from the NOAP**

Observations	L18 (2019 — 2021)	L18 (2022 — Apr-2023)	L18 (May-2023 — Jun- 2024)
Observations	5669	1703	1007
Sessions	939	398	304
Obs./Ses. ratio	6.04	4.3	**3.31**
Objects	505	254	191
Nights	235	88	108
Mean AM_calc*	17.41^m	17.55^m	$\mathbf{17.93^m}$
Median AM_calc	17.61^m	17.85^m	$\mathbf{18.26^m}$
Percentile by level 0.9 for AM_calc	18.59^m	18.60^m	$\mathbf{19.06^m}$
Mean V_HOR**, arcsec/min	17.45	16.94	16.84
Median V_HOR, arcsec/min	8.18	8.36	10.29
Percentile by level 0.9 for V_HOR, arcsec/min	39.90	38.27	35.12

* — calculated apparent magnitude of observed NEOs; ** — velocity of apparent NEO's motion according to NASA Jet Propulsion Laboratory ephemerides [2].

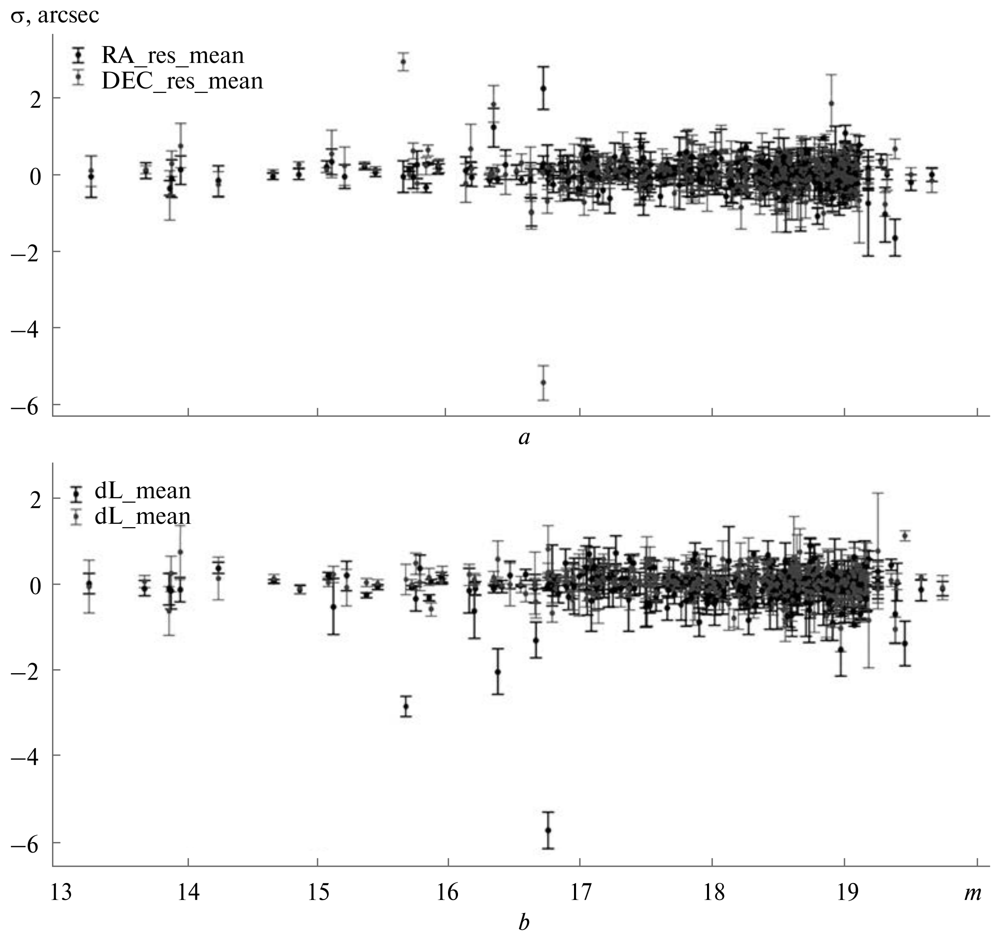

Figure 3. Dependence of the observation accuracy for the L18 facility in 2023—2024 on the apparent brightness of the observed NEOs: *a* — RA, Dec; *b* — along (dL) and cross (dN) track. The raw data from the NEODys-2 website were obtained and processed by the Analyzer pipeline from NOAP

apparent magnitude of the observed NEOs. Fig. 3 shows the dependence of the accuracy of observations on the apparent magnitude for the L18 facility in 2023—2024. The dots show the average error values for each session (the set of observations for one NEO per night) with error limits at the level of one root mean square.

For the majority of objects, there is a noticeable absence of a significant correlation between the brightness and the accuracy of positional observations. This is explained by the fact that the SNR for these observations, due to the use of the "shift-and-stack" technique and the peculiarities of the observation planning algorithms, remains almost at the same level.

The changes introduced had an even greater effect on the qualitative set of the observed NEOs. Table 1 shows the main statistics for the L18 facility, where the new observation planning algorithms were tested. The first column shows the statistics of observations before the introduction of automatic planning, the second — with the use of automatic planning, and the third — with the use of automatic planning and the new algorithms for selecting observed NEOs. It is clearly seen that a significant decrease in the brightness of the observed objects (highlighted in bold) leads to a decrease in the number of observed NEOs per night and the number of observations per session. The effect of brightness weakening itself is associated with the introduction of new planning algorithms allowing a more correct selection of visible NEOs with low brightness and also with the fact that such objects usually have a higher priority.

CONCLUSION AND PLANS FOR THE FUTURE

The ability to plan NEO observations for several observatories (facilities) at once has significantly increased the speed of this process without reducing its quality. A new algorithm for selecting NEOs for observation has made it possible to increase the limiting magnitude of observed objects significantly.

Further work should be focused on the following:

- software code optimization;
- correction of errors that were detected during the use of NOAP;
- changing the algorithm for obtaining data from NEOCP;
- GUI (after the transition to “one-button planning” and changes to the configuration file format, this point has partially lost its relevance);
- Integration with the Analyzer for priorities calculations;
- Improvement of an adaptive algorithm for filtering the NEOs that can be observed with this telescope.

REFERENCES

1. Heinze A. N., Metchev S., Trollo J. (2015). Digital Tracking Observations can Discover Asteroids 10 Times Fainter than Conventional Searches. *Astron. J.*, **150**, 125. DOI: https://doi.org/10.1088/0004-6256/150/4/125.
2. Horizons System. URL: https://ssd.jpl.nasa.gov/horizons/ (Last accessed: 10.10. 20240).
3. Kozhukhov O. M., Medina M. S. (2023). NOAP — Script Package for Planning and Analysis of NEO Observations. *Space Science and Technology*, **29**, № 6 (145), 80—90. DOI: https://doi.org/10.15407/knit2023.06.080.
4. Krisciunas K., Schaefer B. E. (1991). A Model of the Brightness of Moonlight. *Publ. Astron. Soc. Pacif.*, **103**, 1033—1039.
5. McLean I. (2008). *Electronic Imaging in Astronomy. Detectors and Instrumentation* (2 ed.). Berlin: Springer-Praxis.
6. NEODyS-2. URL: https://newton.spacedys.com (Last accessed: 11.10. 2024).
7. Parrot D. Tycho Tracker: A New Tool to Facilitate the Discovery and Recovery of Asteroids Using Synthetic Tracking and Modern GPU Hardware. URL: https://drive.google.com/file/d/1ApjYChayGpL9Y9H85wQBjel3n9z0UT2B/view (Last accessed: 15.09.2024).
8. Schroeder D. (1999). *Astronomical Optics (Second Edition)*. USA: Academic Press.
9. The NEO Confirmation Page. URL: https://minorplanetcenter.net/iau/NEO/toconfirm_tabular.html (Last accessed: 11.10.2024).
10. Wang B., Zhao H. B., Li B. (2017). Detection of Faint Asteroids Based on Image Shifting and Stacking Method. *Acta Astron. Sinica.*, **58**, 5, 95—107.
11. Yanagisawa T., Nakajima A., Kadota K., et al. (2005). Automatic Detection Algorithm for Small Moving Objects. *Pub. Astron. Soc. Jap.*, **57**, 399—408.
12. Zhai C., Shao M., Nemati B., et al. (2014). Detection of a Faint Fast-Moving Near-Earth Asteroid Using the Synthetic Tracking Technique. *Astrophys. J.*, **792**, 60. DOI: https://doi.org/10.1088/0004-637X/792/1/60.

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NOAP PLANNER 0.6.5 — ОСОБЛИВОСТІ ПЛАНУВАННЯ СПОСТЕРЕЖЕНЬ НАВКОЛОЗЕМНИХ ОБ'ЄКТІВ ОДНІЄЮ КНОПКОЮ

Минулого року у даному журналі було представлено пакет Python-скриптів NOAP (NEO Observation Analyzer and Planner), призначений для автоматизованого планування та аналізу спостережень навколоземних об'єктів (NEO). За останній рік цей пакет зазнав істотних змін, зокрема було оновлено конвеєр планування. Основною метою оновлення було максимальне спрощення та автоматизація процесу планування спостережень, а також підвищення точності вибору об'єктів для спостереження. У даній статті висвітлюються головні зміни, внесені в конвеєр Planner, і обговорюються особливості автоматизованого планування спостережень NEO для телескопів з невеликою апертурою.

Було розроблено алгоритм для автоматизованої обробки даних з веб-сторінки сайту Центру малих планет NEOCP, що дозволяє виявляти нові об'єкти, які потребують підтвердження, значно швидше. Крім того, було створено адаптивний алгоритм фільтрації NEO з урахуванням швидкості їхнього видимого руху та передбачуваної яскравості. Це дає можливість покращити межу зіркової величини для більш повільних NEO та відхиляти об'єкти, які не можна спостерігати на даному телескопі через співвідношення «швидкість — яскравість».

У статті також обговорюється нова функція автоматизованого розрахунку ефемерид для швидких об'єктів, що дозволяє уникати втрати спостережень через занадто швидкий рух об'єкта через поле зору телескопа. Завдяки такому підходу, можливість помилки під час планування була мінімізована, а сама процедура стала доступною для одночасного планування спостережень для кількох обсерваторій.

Впровадження нових алгоритмів дозволило значно підвищити ефективність спостережень, особливо для об'єктів із низькою яскравістю. У дослідженні наведені приклади застосування нового планувальника для станції L18 та продемонстровано статистичні дані, що підтверджують зростання точності та якості спостережень.

Ключові слова: навколоземні об'єкти, оптичні спостереження.