UDC 004.048

DATA MINING OF THE PRIMARY ORBITS OF THE SOLAR SYSTEM OBJECTS USING THE COLITEC SOFTWARE AND THE VÄISÄLÄ METHOD

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Abstract. The chapter is devoted to the processing pipeline for data mining of the primary orbits and discovery of the new Solar System objects using the CoLiTec software and classical Väisälä method. The first step of a such processing pipeline is performing the sequential astronomical observations and the classical astrometric data reduction. It is implemented as a combination of the general mathematical algorithms and methods for processing of the astronomical frames incapsulated in the CoLiTec software. It contains the inverse median filter, astronomical calibration with usage of the calibration master-frames (bias, dark, flat, dark-flat), detection of the astronomical objects and its trajectories in series of frames and other very useful and important features. After that the especial parameters of the object's orbit (right ascension and declination) are calculated at the certain time. When we receive at least two observations of the same object under study at different moments, the classic Väisälä algorithm can be applied. For this, the primary orbit from the two nearest observations is calculated. Then the geocentric rectangular coordinates and the appropriate geocentric velocity components are computed. This give us an opportunity for determining the Keplerian elements of orbit of the investigated object at any time we are interested in. The developed algorithm is implemented as a processing pipeline that includes a combination of the CoLiTec software and created tool with encapsulation of the Väisälä method. The created processing pipeline for data mining of *the primary orbits and discovery of the new Solar System objects using the CoLiTec software and classical Väisälä method is practically verified. Using it a few new asteroids are first reported and a few lost small bodies of the Solar System are found in the Kyiv comet station and the Odesa - Mayaky observatory.*

Keywords: *Data mining, processing pipeline, astronomical observations, CoLiTec software, Väisälä method, image processing, image calibration, astrometric reduction, photometric reduction, object detection, positional coordinates, orbit determination, Solar System objects*

1. Introduction

The asteroid-comet hazard is a big potential problem in the XXI century. It leads to the developing astronomical scientific direction like an image processing, which includes the following algorithms for astrometric reduction [1], photometric reduction [2], detection or even discovery of the Solar System objects [3], etc.

A common goal of all scientific and technological algorithms is to automate as much as available processes without any human actions. In general cases it can be done by the different astronomical scientific processing pipelines. In these pipelines the various data mining [4] and knowledge discovery in databases (KDD) [5] tasks are used for speeding up and optimizing the astronomical data processing.

The astronomical scientific information is collected from the different historical archives, clusters, Virtual Observatories [6], clouds, astronomical astrometric and photometric catalogues [7], different servers and other storages. Almost all astronomical scientific observations are created by the charge-coupled device (CCD) [8] and performed during the specified observational period of the investigated small celestial objects of the Solar System (SSOs) [9] (like, comets or asteroids [10]), as well as the artificial satellites [11]. After performing the series of observations of the investigated SSOs it is required to analyze the results of observation, which can include the period and shape of rotations determining of such investigated SSOs.

That is why it is required to create a mathematical method to determine a primary orbit and discovery of the new Solar System objects using the CoLiTec software and the classical Väisälä method. Such a method gives a possibility for estimating the geocentric rectangular positional coordinates of a SSO under study with and calculating the different Keplerian elements of the SSO's orbit. At the same time this algorithm can improve the conditional expectation of the correct discovery [12] of the real SSOs. The Väisälä algorithm is a very useful algorithm when used in the different situations [13]. Its importance becomes noticeable with the particularly short observation arcs, which are insufficient to confirm an exact orbit and predict a position of the investigated small astronomical Solar System object during the next week. This chapter aims to the analysis of main focuses and features of the processing pipeline for data mining of the primary orbits and discovery of the new Solar System objects using the CoLiTec software and classical Väisälä method.

Section 2 presents the literature review with mentioning advantages and disadvantages of the reviewed papers. Section 3 elaborates an architecture of the processing pipeline for data mining of the primary orbits and discovery of the new Solar System objects. Detailed description of steps of the processing pipeline are also presented in this section as well as the description of the Väisälä algorithm. This section also aims to the main features and advantages of the CoLiTec software for the astronomical data processing purposes.

Section 4 presents the results received during processing astronomical data with the different SSOs from the Kyiv comet station and the Odesa - Mayaky observatory. Such results include identifiers of the new asteroids that were firstly discovered and the lost SSOs that were found again and re-discovered. The chapter ends with a conclusion in section 5, which illustrates the conclusions and outlines of the future work and research as well as possibilities for future investigations and enhancements.

2. Literature review

Each Solar System object presented in a CCD-frame has a typical form of its image [14]. The common methods for the image processing [15] are developed for detection/recognition such images of SSOs and an estimation of their positional and motion parameters [16]. Such methods are based on the analysis of only those pixels that potentially belong to the investigated object. The disadvantages of such methods are very low accuracies when the typical form of object has a different shape [17].

The methods for pixelization and segmentation by the aperture brightness [18] will work only with a single image of each SSO. A method for the matched filtration [19] uses a model of the object's image, which is analytically determined. The disadvantages of the methods above are the big complexity and low accuracy during the processing, when an image has a several peaks of magnitude. Methods for the Wavelet analysis [20] or even time series analysis [21] are not so effective, because we do not have a big volume of the input data to be analyzed. Also, the disadvantage of such algorithms is the corrupting of the general statistics and possibility to process only clear measurements without any deviations in the typical form of image.

The methods for assessing the aperture brightness [22] of object's images will work only with a single image of each SSO. Any methods for the matched filtration [23] and high-frequency filtration [24], which are devoted to the improving the quality of corrupted images are very resource consuming. The disadvantages of the methods are the big complexity and low accuracy during the astronomical data processing, when an object's image has a several peaks of magnitude.

Computer vision methods [25] have the main disadvantage that they are not able to provide the required level of processing speed using standard libraries. Classical methods for object image recognition [26, 27] require analysis of all pixels of potential objects to determine their typical shape. This also significantly affects processing time. In the case of heterogeneity of the standard typical shape or form, objects become confused, and this, in turn, increases the processing time of both the strobe with the image of the object and the entire frame. Methods for estimating of the image parameters [28, 29] are based on the analysis of only those pixels that potentially belong to the Solar System object under study. Their disadvantage is the inability to determine specific pixels and reject those whose intensity exceeds a specified limit value initially accurately. Because of this, the processing time of each frame increases. The authors of [30] use automatic selection of a reference point as preprocessing to select calibration frames. This algorithm requires quite a lot of execution time because it involves first analyzing the image to find reference points. Next, these points are identified with astronomical catalogs to obtain coordinates on the celestial sphere. After this, the telescope is pointed at the coordinates of the desired area of the sky and takes calibration frames. This entire algorithm requires the coherence of all systems, including the automated telescope mount. At the same time, if there are artifacts in the images, these control points may be false, this leads to an increase in processing time (to search for new control points), or even the impossibility of executing the algorithm. The median pooling algorithm [31] proposes to accumulate a large number of frames for pre-calibration to get rid of real objects, leaving only a uniform background signal. The disadvantage of this approach is the fact that the formation and use of data arrays for each such image requires huge volume of RAM. Any methods for the machine learning [32] and pattern recognition [33] also require a big amount of astronomical data for training. The problem of such methods that astronomical image has a lot of artifacts, so there are a lot of false objects are detected in series of frames.

3. Data mining of the primary orbits of the Solar System objects

Astronomical image calibration is a critical process in astrophotography and observational astronomy [34]. These calibration frames are used to correct different imperfections and artifacts introduced during the image acquisition process, ensuring the accuracy and quality of the final images:

- **Bias Frames**. Bias frames capture the electronic signal present in the camera sensor when no light is allowed to enter the telescope. They record the baseline electronic offset or zero signal level of the sensor. Bias frames help correct for the sensor's inherent electronic noise, such as readout noise and amplifier offsets;
- **Dark Frames**. Dark frames are images taken with the telescope or camera covered, capturing the thermal signal produced by the sensor itself. This signal is a result of heat generating random electronic noise in the detector. Dark frames help in correcting thermal noise, hot pixels, and other sensor-specific imperfections;
- **Flat Frames**. Flat frames are images of a uniformly illuminated surface or a blank, evenly illuminated part of the sky. They are used to correct for variations in sensitivity across the camera sensor, as well as for dust specks or imperfections in the optical system. Flat frames help to normalize the pixel-to-pixel sensitivity differences in the sensor and remove any vignetting or dust shadows.

The calibration process involves the following steps:

1. **Acquisition**: Bias, dark, and flat frames are captured under specific conditions matching the settings used for the actual astrophotography session. It's important to ensure that the exposure times and temperatures match those of the light frames (images of celestial objects).
2. **Subtraction**: The bias frame is subtracted from all the frames (light, dark, and flat) to remove the electronic offset and noise present in the images.
3. **Dark Subtraction**: Dark frames are subtracted from the light frames to eliminate the thermal signal caused by the camera sensor's temperature during image acquisition.
4. **Flat Fielding**: Flat frames are used to normalize the response of the sensor. Light frames are divided by the normalized flat frames to correct variations in pixel

sensitivity and eliminate artifacts caused by dust, vignetting, or optical imperfections.

5. **Post-Processing**: Once the calibration process is completed, further image processing techniques, such as stacking, alignment, and color calibration, are often applied to enhance the final image quality.

Calibrating images with bias, dark, and flat frames is crucial in producing high-quality astrophotographs and ensuring accurate scientific analysis by removing unwanted noise and artifacts introduced during the imaging process.

In the developed algorithm we performed the different actions for the astronomical data calibration, like calibration dark frames subtracting, calibration bias frames subtracting and calibration flat frames fielding/dividing [35].

Every astronomical observation of the investigated astronomical object provides the topocentric directions to it:

$$\begin{cases} X_i = -G_{1i}\cos\varphi_i\cos\theta_i, \\ Y_i = -G_{1i}\cos\varphi_i\sin\theta_i, \\ Z_i = -G_{2i}\sin\varphi_i, \end{cases} \tag{1}$$

where a coefficient *G* and a local sidereal time (*θ*) are calculated by the following equations:

$$\begin{aligned} G_{1i} &= \frac{a_e}{\sqrt{1-\left(2f-f^2\right)\sin^2\varphi_i}} + H_i, \\ G_{2i} &= \frac{\left(1-f\right)^2 a_e}{\sqrt{1-\left(2f-f^2\right)\sin^2\varphi_i}} + H_i, \end{aligned} \tag{2}$$

$$\theta_i = \theta_{g0} + \frac{d\theta}{dt}\left(t_i - t_0\right) + \lambda_{Ei}, \tag{3}$$

where φi, λEi are the geodetic latitude and longitude of the observer;

Hi is the altitude of the observer;

Earth ellipsoid model recommended by the IERS [36];

semi-major axis (aE) of 6378171.364331512 m;

inverse of polar flattening (1/f) of 297.7736994668283;

θg0 is Greenwich Mean Sidereal Time (GMST).

After astrometric reduction to the Earth center, we received the right ascension (α_i) (RA) and declination (δ_i) (DE) for the current time (t_i).

This gives us a possibility to create a system of connection equations:

$$\begin{cases} \rho_i\cos\alpha_i\cos\delta_i = x_i + X_i, \\ \rho_i\sin\alpha_i\cos\delta_i = y_i + Y_i, \\ \rho_i\sin\delta_i = z_i + Z_i, \end{cases} \tag{4}$$

where X_i, Y_i, Z_i are rectangular geocentric equatorial coordinates of the Sun;

x_i, y_i, z_i are rectangular heliocentric equatorial coordinates of an investigated astronomical object.

The geocentric coordinates of the Sun can be taken from the Solar System model. And the geocentric distances (ρ_i) and heliocentric coordinates (x_i, y_i, z_i) of an investigated astronomical are unknown in system 4. General representation of the Väisälä algorithm requires the 2 nearest astronomical observations of the same investigated object at times t_1 and t_2. So, we can calculate the primary orbit from such two observations using a set of the following parameters (t_1, α_1, δ_1, t_2, α_2, δ_2).

To calculate the geocentric rectangular coordinates of an investigated object we can use the following system of equations:

$$\begin{cases} x_2 = \Delta_2 \cos\alpha_2 + X_2, \\ y_2 = \Delta_2 \sin\alpha_2 + Y_2, \\ z_2 = \Delta_2 \tan\delta_2 + Z_2, \end{cases} \tag{5}$$

where $\Delta_2 = \rho_2 \cos\delta_2$.

To calculate the geocentric velocity components of an object we can use the following system:

$$\begin{cases} \dot{x}_2 = \dfrac{\Delta_1 \cos\alpha_1 - F_1 x_2 + X_1}{G_1}, \\ \dot{y}_2 = \dfrac{\Delta_1 \sin\alpha_1 - F_1 y_2 + Y_1}{G_1}, \\ \dot{z}_2 = \dfrac{\Delta_1 \tan\delta_1 - F_1 z_2 + Z_1}{G_1}, \end{cases} \tag{6}$$

$$\begin{gathered} \Delta_1 = \frac{F_1 r_2 + X_1 x_1 + Y_1 y_1 + Z_1 z_1}{x_2 \cos\alpha_1 + y_2 \sin\alpha_1 + z_2 \tan\delta_1}, \\ F_1 = 1 - A\tau^2, G_1 = \tau - B\tau^3, \\ A = \frac{r^3}{2}, B = \frac{A}{3}, \end{gathered} \tag{7}$$

where $\tau = k\left(t_1 - t_2\right)$ is a time interval between two nearest observations;

k is a gravitation constant.

The determined parameters $\left(x_2, y_2, z_2, \dot{x}_2, \dot{y}_2, \dot{z}_2\right)$ will be used for calculation the Keplerian elements of the orbit of an investigated object at a time t_2.

An architecture of a processing pipeline for data mining of the primary orbits and discovery of the new Solar System objects using the CoLiTec software and classical Väisälä method is presented in Fig. 1. Such method contains the next steps:

1. Perform the observations of the investigated SSOs.
2. Perform the classic data reduction process using the calibration bias, flat, and dark CCD frames.
3. Perform the astrometric reduction of the investigated SSOs using the CoLiTec software.

4. Calculation of a primary orbit of the investigated SSOs by the Väisälä algorithm implemented as a tool.
5. Repeat the astronomical observations of the investigated SSOs to confirm a discovery of the new SSOs.

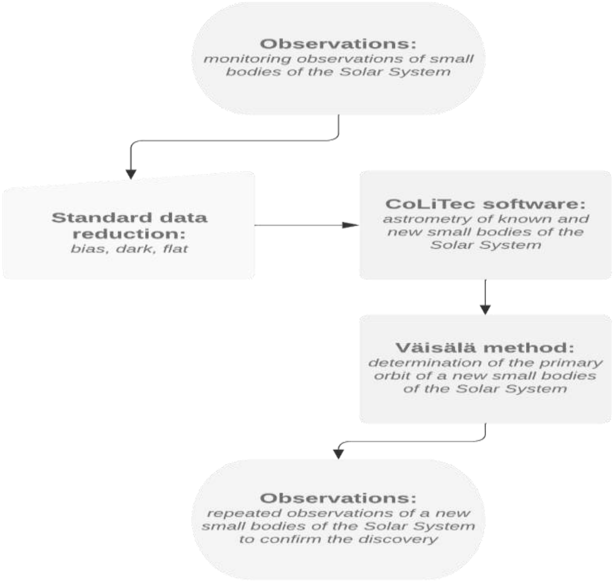


Figure 1. *Architecture of a processing pipeline for data mining of the primary orbits and discovery of the new Solar System objects using the CoLiTec software and classical Väisälä method*

4. Results

The created algorithm to determine a primary orbit and discoveries of the SSOs using the Väisälä algorithm works in combination with the CoLiTec software (https://colitec.space) [37]. The specific functional features related to the mathematical method for determining the primary orbits and discovery of asteroids in the CoLiTec software are:

- processing images with the very wide FOV (<10 degrees^2);
- automated frame calibration [9];
- cosmetic frame correction;
- track-and-stack feature;
- brightness equalization [2];
- background alignment;

- astronomical image filtering [26];
- determining the contours of objects [38];
- image recognition [33];
- typical shape formation [14];
- detection of the moving objects (with near-zero, normal, fast apparent motion) [39];
- fully automated robust method of the astrometric reduction;
- fully automated robust method of the photometric reduction [23];
- support of the multi-threaded processing;
- On-Line Data Analysis System (OLDAS) for managing the processing pipeline;
- transferring of astronomical data with intermediate storage.

More extended details about the CoLiTec software are presented in these papers [40, 41, 42] and research [43]. The high-level processing pipeline with the developed modules and implemented methods of the CoLiTec software is presented in the Fig. 2.

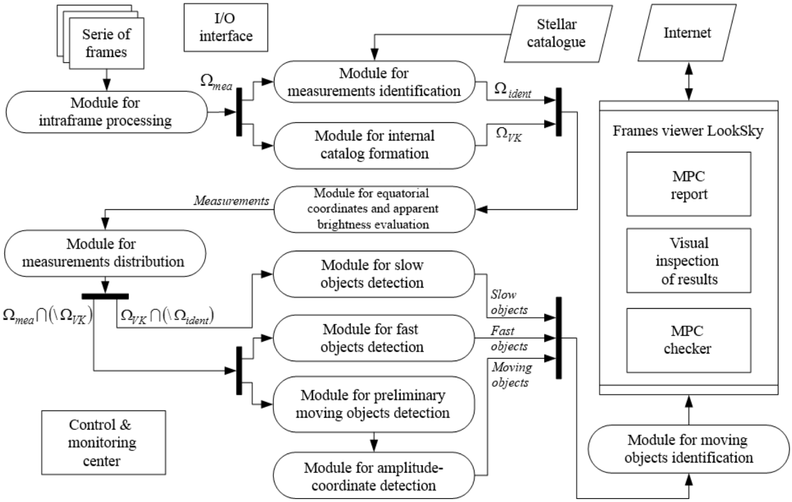


Figure 2. *The high-level processing pipeline of the CoLiTec software*

The CoLiTec software is installed at the different telescopes at the various observatories in Ukraine and around the world:

- OMT-800 and AZT-3 telescopes installed at the Odesa-Mayaky observatory [44];
- SANTEL-400AN telescope installed at the ISON-NM observatory;
- ISON-Uzhgorod [45];
- VNT and Celestron C11 telescopes installed at the Vihorlat Observatory [34];
- PROMPT-8 telescope installed at Cerro Tololo observatory [46];

- NARIT (National Astronomical Research Institute of Thailand) [47];
- AZT8 and Takahashi BRC-250M telescopes.

All listed above telescopes installed at the observatories have the official identifiers received from the Minor Planet Center (MPC) (https://minorplanetcenter.net) – MPC code from the International Astronomical Union (IAU) (https://iau.org).

Astronomical observations were made on the OMT-800 telescope installed at the Mayaky observational station of the Astronomical Observatory of the Odesa I. I. Mechnykov National University.

The official MPC code of the Odesa-Mayaky station is 583 (see Fig. 3) (https://www.minorplanetcenter.net/iau/lists/ObsCodesF.html):

```
Code  Long.     cos       sin       Name
580  15.4936   0.68242   +0.72862   Graz
581  22.80     0.830     -0.556     Sedgefield
582   1.2408   0.61682   +0.78447   Orwell Park
583  30.2717   0.69087   +0.72056   Odesa-Mayaky
584  30.2946   0.50213   +0.86189   Leningrad
585  30.52462  0.640067  +0.765748  Kyiv comet station
586   0.1423   0.73358   +0.67799   Pic du Midi
587   9.22918  0.697459  +0.714479  Sormano
588  11.25     0.715     +0.697     Eremo di Tizzano
589  12.64369  0.738223  +0.672386  Santa Lucia Stroncone
590   7.46     0.678     +0.734     Metzerlen
```

Figure 3. *The official MPC codes of the Odesa-Mayaky observatory*

The 0.8-m main hyperbolic mirror is installed at the OMT-800 telescope and has a useful focus ratio as f = 1/2.7. The FLI ML09000 CCD-camera is used as an image CCD-detector along with a 4-lens field corrector for a primary focus, which allows receiving the field of view (FOV) as 58.6'×58.6' and the scale of image as 1.15 arcseconds per pixel. The real photography of the OMT-800 telescope is presented in Fig. 4. During the astronomical observations at the OMT-800 telescope and research after processing the results, the next lost SSOs were found again:

- 2012 FN61 = 2010 VP219 (MPS 441842);
- 2017 AB8 = 2014 OD380 (MPS 525811).

Figure 4. *The real photography of the OMT-800 telescope*

Astronomical observations were made on the AZT-8 telescope installed at the Kyiv comet station of the “Lisnyky” observational station of the Taras Shevchenko National University of Kyiv. The official MPC code of the Kyiv comet station is 585 (see Fig. 5) (https://www.minorplanetcenter.net/iau/lists/ObsCodesF.html):

Code	Long.	cos	sin	Name
580	15.4936	0.68242	+0.72862	Graz
581	22.80	0.830	-0.556	Sedgefield
582	1.2408	0.61682	+0.78447	Orwell Park
583	30.2717	0.69087	+0.72056	Odesa-Mayaky
584	30.2946	0.50213	+0.86189	Leningrad
585	30.52462	0.640067	+0.765748	Kyiv comet station
586	0.1423	0.73358	+0.67799	Pic du Midi
587	9.22918	0.697459	+0.714479	Sormano
588	11.25	0.715	+0.697	Eremo di Tizzano
589	12.64369	0.738223	+0.672386	Santa Lucia Stroncone
590	7.46	0.678	+0.734	Metzerlen

Figure 5: The official MPC codes of the Kyiv comet station

The installed AZT-8 telescope is a telescope-reflector. The FLI PL4710 CCD-camera (63.5 mm) was used as an image CCD-detector, which allows receiving the FOV as 16.2'×16.7' and the scale of image as 0.948 arcseconds per pixel.

The real photography of the AZT-8 telescope is presented in Fig. 6.

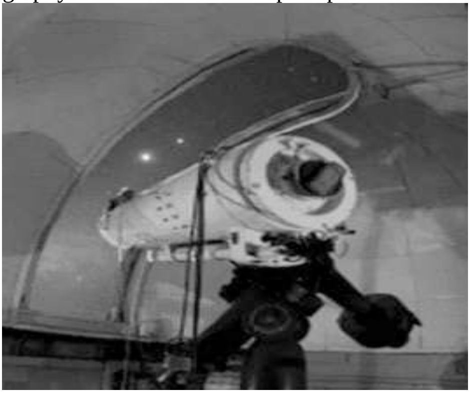


Figure 6. *The real photography of the AZT-8 telescope*

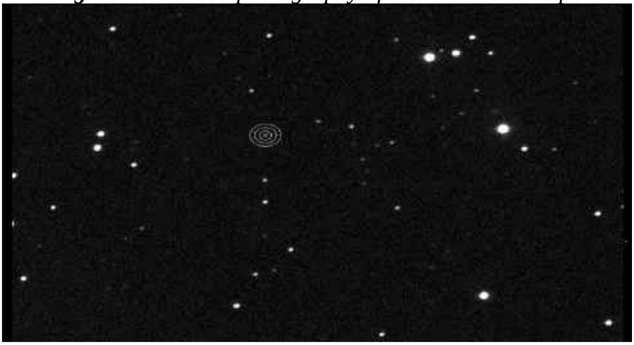


Figure 7. *The detected astronomical object #3548*

During the astronomical observations on the Kyiv comet station and research after processing the results, the new asteroid 2017 SV39 (MPS 828365) was firstly discovered and the next lost SSOs were found again:

- (536266) = 2007 HU101 = 2015 CX48 = 2017 ST39 (MPS 891037);
- (540584) = 2000 WN134 = 2007 XY37 = 2010 RD162 = 2015 DH168 = 2017 TS7 (MPS 23003).

Table 2
The main parameters of the detected astronomical object #3548

Parameter	Value
Epoch (Julian date)	2460400.5
Perihelion (Julian date)	2459673.41574
Argument of perihelion (°)	27.92959
Ascending node (°)	43.54101
Inclination (°)	8.05416
Eccentricity	0.0912182
Perihelion distance (AU)	4.7350370
Tisserand w.r.t. Jupiter	3.0
Semimajor axis (AU)	5.2103122
Mean anomaly (°)	60.25501
Mean daily motion (°/day)	0.08287210
Aphelion distance (AU)	5.686
Period (years)	11.89
P-vector [x]	0.32097397
P-vector [y]	0.84074355
P-vector [z]	0.43603439
Q-vector [x]	-0.94215715
Q-vector [y]	0.23653103
Q-vector [z]	0.23747207
Absolute magnitude	9.83
Phase slope	0.15

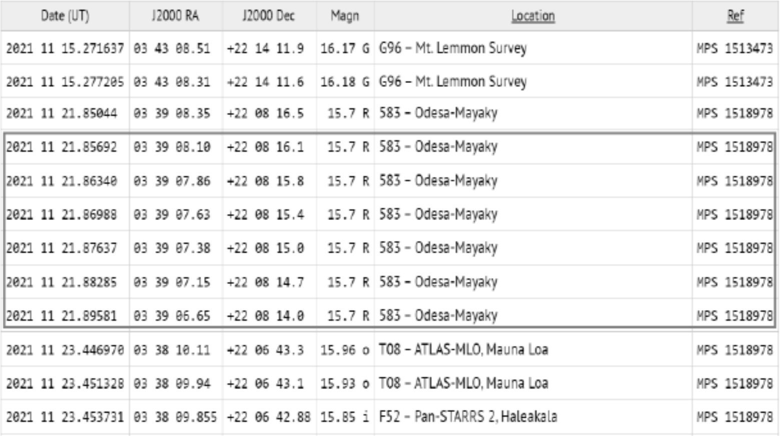
There are different examples of the discovered objects by the Odesa-Mayaky observatory (MPC code is 583) are presented below.

The detected astronomical object #3548 is presented in Fig. 7.

The main parameters of the detected astronomical object #3548 (orbit type: Jupiter Trojan) are presented in Table 1. All such parameters were received from the official MPC web-site – https://www.minorplanetcenter.net/db_search/show_object?utf8=%E2%9C%93&object_id=3548.

The observation details of the detected astronomical object #3548 by the Odesa-Mayaky observatory (MPC code is 583) are presented in Fig. 8 below.

The new detected asteroid 2017 QX33 (MPS 813479) is presented in Fig. 9.



Date (UT)	J2000 RA	J2000 Dec	Magn	Location	Ref
2021 11 15.271637	03 43 08.51	+22 14 11.9	16.17 G	G96 – Mt. Lemmon Survey	MPS 1513473
2021 11 15.277205	03 43 08.31	+22 14 11.6	16.18 G	G96 – Mt. Lemmon Survey	MPS 1513473
2021 11 21.85044	03 39 08.35	+22 08 16.5	15.7 R	583 – Odesa-Mayaky	MPS 1518978
2021 11 21.85692	03 39 08.10	+22 08 16.1	15.7 R	583 – Odesa-Mayaky	MPS 1518978
2021 11 21.86340	03 39 07.86	+22 08 15.8	15.7 R	583 – Odesa-Mayaky	MPS 1518978
2021 11 21.86988	03 39 07.63	+22 08 15.4	15.7 R	583 – Odesa-Mayaky	MPS 1518978
2021 11 21.87637	03 39 07.38	+22 08 15.0	15.7 R	583 – Odesa-Mayaky	MPS 1518978
2021 11 21.88285	03 39 07.15	+22 08 14.7	15.7 R	583 – Odesa-Mayaky	MPS 1518978
2021 11 21.89581	03 39 06.65	+22 08 14.0	15.7 R	583 – Odesa-Mayaky	MPS 1518978
2021 11 23.446970	03 38 10.11	+22 06 43.3	15.96 o	T08 – ATLAS-MLO, Mauna Loa	MPS 1518978
2021 11 23.451328	03 38 09.94	+22 06 43.1	15.93 o	T08 – ATLAS-MLO, Mauna Loa	MPS 1518978
2021 11 23.453731	03 38 09.855	+22 06 42.88	15.85 i	F52 – Pan-STARRS 2, Haleakala	MPS 1518978

Figure 8. *The observation details of the detected astronomical object #3548 by the Odesa-Mayaky observatory*

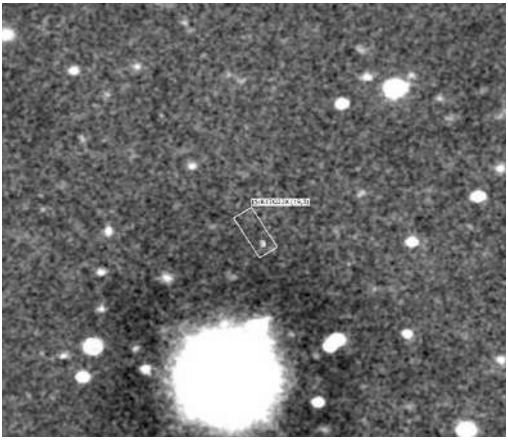


Figure 9. *The new detected asteroid 2017 QX33 (MPS 813479)*

The main parameters of the new detected asteroid 2017 QX33 (orbit type: Jupiter Trojan) are presented in Table 2.

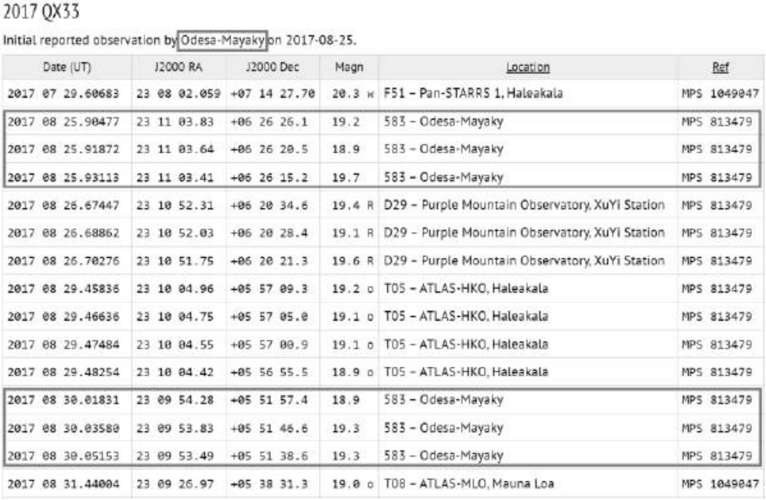
All such parameters were received from the official MPC web-site – https://www.minorplanetcenter.net/db_search/show_object?utf8=%E2%9C%93&object_id=2017+QX33.

Table 2

The main parameters of the new detected asteroid 2017 QX33

Parameter	Value
Epoch (Julian date)	2460400.5
Perihelion (Julian date)	2459294.27298
Argument of perihelion (°)	173.50876
Ascending node (°)	193.83235
Inclination (°)	7.66939
Eccentricity	0.2957998
Perihelion distance (AU)	1.6009058
Tisserand w.r.t. Jupiter	3.5
Semimajor axis (AU)	2.2733673
Mean anomaly (°)	318.08555
Mean daily motion (°/day)	0.28754090
Aphelion distance (AU)	2.946
Period (years)	3.43
P-vector [x]	0.99156124
P-vector [y]	0.11213188
P-vector [z]	0.06505954
Q-vector [x]	-0.12565127
Q-vector [y]	0.95478909
Q-vector [z]	0.26942450
Absolute magnitude	18.58
Phase slope	0.15

The observation details of the new detected asteroid 2017 QX33 by the Odesa-Mayaky observatory (MPC code is 583) are presented in Fig. 10 below.



2017 QX33

Initial reported observation by Odesa-Mayaky on 2017-08-25.

Date (UT)	J2000 RA	J2000 Dec	Magn	Location	Ref
2017 07 29.60683	23 08 02.059	+07 14 27.70	20.3 w	F51 – Pan-STARRS 1, Haleakala	MPS 1049047
2017 08 25.90477	23 11 03.83	+06 26 26.1	19.2	583 – Odesa-Mayaky	MPS 813479
2017 08 25.91872	23 11 03.64	+06 26 20.5	18.9	583 – Odesa-Mayaky	MPS 813479
2017 08 25.93113	23 11 03.41	+06 26 15.2	19.7	583 – Odesa-Mayaky	MPS 813479
2017 08 26.67447	23 10 52.31	+06 20 34.6	19.4 R	D29 – Purple Mountain Observatory, XuYi Station	MPS 813479
2017 08 26.68862	23 10 52.03	+06 20 28.4	19.1 R	D29 – Purple Mountain Observatory, XuYi Station	MPS 813479
2017 08 26.70276	23 10 51.75	+06 20 21.3	19.6 R	D29 – Purple Mountain Observatory, XuYi Station	MPS 813479
2017 08 29.45836	23 10 04.96	+05 57 09.3	19.2 o	T05 – ATLAS-HKO, Haleakala	MPS 813479
2017 08 29.46636	23 10 04.75	+05 57 05.0	19.1 o	T05 – ATLAS-HKO, Haleakala	MPS 813479
2017 08 29.47484	23 10 04.55	+05 57 00.9	19.1 o	T05 – ATLAS-HKO, Haleakala	MPS 813479
2017 08 29.48254	23 10 04.42	+05 56 55.5	18.9 o	T05 – ATLAS-HKO, Haleakala	MPS 813479
2017 08 30.01831	23 09 54.28	+05 51 57.4	18.9	583 – Odesa-Mayaky	MPS 813479
2017 08 30.03580	23 09 53.83	+05 51 46.6	19.3	583 – Odesa-Mayaky	MPS 813479
2017 08 30.05153	23 09 53.49	+05 51 38.6	19.3	583 – Odesa-Mayaky	MPS 813479
2017 08 31.44004	23 09 26.97	+05 38 31.3	19.0 o	T08 – ATLAS-MLO, Mauna Loa	MPS 1049047

***Figure 10.** The observation details of the new detected asteroid 2017 QX33 by the Odesa-Mayaky observatory*

The detected astronomical object #21900 is presented in Fig. 11.

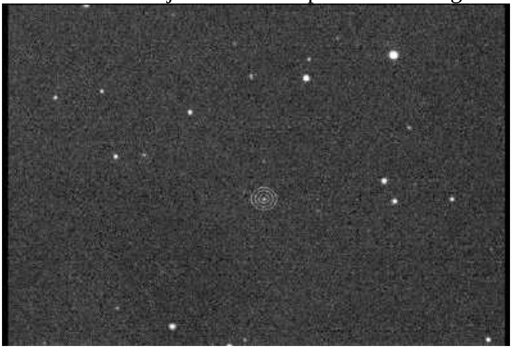


Figure 11. *The detected astronomical object #21900*

The main parameters of the detected astronomical object #21900 (orbit type: Jupiter Trojan) are presented in Table 3.

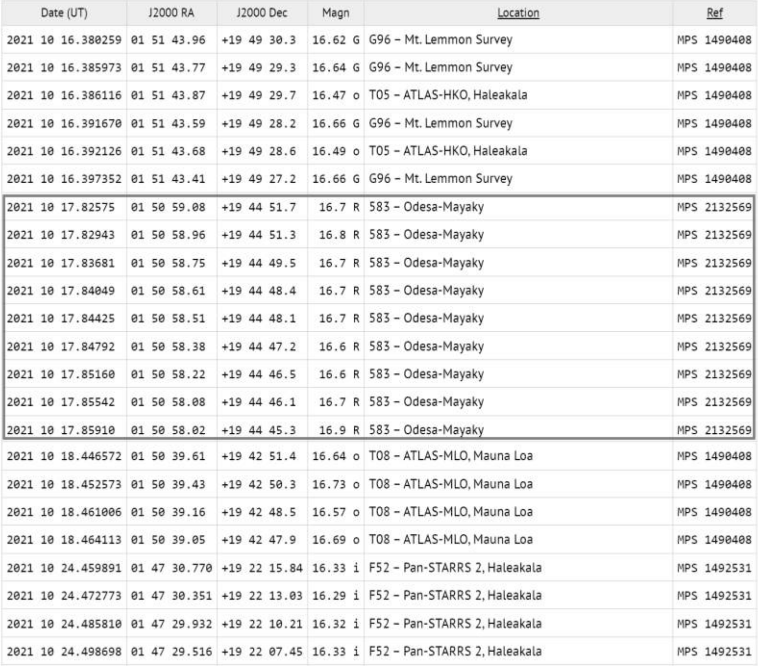
All such parameters were received from the official MPC web-site – https://www.minorplanetcenter.net/db_search/show_object?utf8=%E2%9C%93&object_id=21900.

Table 3

The main parameters of the detected astronomical object #21900

Parameter	Value
Epoch (Julian date)	2460400.5
Perihelion (Julian date)	2460053.88476
Argument of perihelion (°)	182.13714
Ascending node (°)	258.55425
Inclination (°)	8.46880
Eccentricity	0.0376942
Perihelion distance (AU)	4.9306527
Tisserand w.r.t. Jupiter	3.0
Semimajor axis (AU)	5.1237899
Mean anomaly (°)	29.45537
Mean daily motion (°/day)	0.08498000
Aphelion distance (AU)	5.317
Period (years)	11.6
P-vector [x]	0.16215070
P-vector [y]	0.90751066
P-vector [z]	0.38746814
Q-vector [x]	-0.97615189
Q-vector [y]	0.20496114
Q-vector [z]	-0.07154318
Absolute magnitude	10.06
Phase slope	0.15

The observation details of the detected astronomical object #21900 by the Odesa-Mayaky observatory (MPC code is 583) are presented in Fig. 12 below.



Date (UT)	J2000 RA	J2000 Dec	Magn	Location	Ref
2021 10 16.380259	01 51 43.96	+19 49 30.3	16.62 G	G96 – Mt. Lemmon Survey	MPS 1490408
2021 10 16.385973	01 51 43.77	+19 49 29.3	16.64 G	G96 – Mt. Lemmon Survey	MPS 1490408
2021 10 16.386116	01 51 43.87	+19 49 29.7	16.47 o	T05 – ATLAS-HKO, Haleakala	MPS 1490408
2021 10 16.391670	01 51 43.59	+19 49 28.2	16.66 G	G96 – Mt. Lemmon Survey	MPS 1490408
2021 10 16.392126	01 51 43.68	+19 49 28.6	16.49 o	T05 – ATLAS-HKO, Haleakala	MPS 1490408
2021 10 16.397352	01 51 43.41	+19 49 27.2	16.66 G	G96 – Mt. Lemmon Survey	MPS 1490408
2021 10 17.82575	01 50 59.08	+19 44 51.7	16.7 R	583 – Odesa-Mayaky	MPS 2132569
2021 10 17.82943	01 50 58.96	+19 44 51.3	16.8 R	583 – Odesa-Mayaky	MPS 2132569
2021 10 17.83681	01 50 58.75	+19 44 49.5	16.7 R	583 – Odesa-Mayaky	MPS 2132569
2021 10 17.84049	01 50 58.61	+19 44 48.4	16.7 R	583 – Odesa-Mayaky	MPS 2132569
2021 10 17.84425	01 50 58.51	+19 44 48.1	16.7 R	583 – Odesa-Mayaky	MPS 2132569
2021 10 17.84792	01 50 58.38	+19 44 47.2	16.6 R	583 – Odesa-Mayaky	MPS 2132569
2021 10 17.85160	01 50 58.22	+19 44 46.5	16.6 R	583 – Odesa-Mayaky	MPS 2132569
2021 10 17.85542	01 50 58.08	+19 44 46.1	16.7 R	583 – Odesa-Mayaky	MPS 2132569
2021 10 17.85910	01 50 58.02	+19 44 45.3	16.9 R	583 – Odesa-Mayaky	MPS 2132569
2021 10 18.446572	01 50 39.61	+19 42 51.4	16.64 o	T08 – ATLAS-MLO, Mauna Loa	MPS 1490408
2021 10 18.452573	01 50 39.43	+19 42 50.3	16.73 o	T08 – ATLAS-MLO, Mauna Loa	MPS 1490408
2021 10 18.461006	01 50 39.16	+19 42 48.5	16.57 o	T08 – ATLAS-MLO, Mauna Loa	MPS 1490408
2021 10 18.464113	01 50 39.05	+19 42 47.9	16.69 o	T08 – ATLAS-MLO, Mauna Loa	MPS 1490408
2021 10 24.459891	01 47 30.770	+19 22 15.84	16.33 i	F52 – Pan-STARRS 2, Haleakala	MPS 1492531
2021 10 24.472773	01 47 30.351	+19 22 13.03	16.29 i	F52 – Pan-STARRS 2, Haleakala	MPS 1492531
2021 10 24.485810	01 47 29.932	+19 22 10.21	16.32 i	F52 – Pan-STARRS 2, Haleakala	MPS 1492531
2021 10 24.498698	01 47 29.516	+19 22 07.45	16.33 i	F52 – Pan-STARRS 2, Haleakala	MPS 1492531

Figure 12. *The observation details of the detected astronomical object #21900 by the Odesa-Mayaky observatory*

5. Conclusions

We present a processing pipeline for data mining of the primary orbits and discovery of the new Solar System objects using the CoLiTec software and classical Väisälä method. The literature review showed the benefits and disadvantages of the existing methods and algorithms. So, we made a decision to improve such algorithms for the better accuracy and quality of detection of the new or lost SSOs.

The first step of such computational algorithm is to perform the observations and the standard data reduction. It was performed in scope of the common mathematical methods for the astronomical image processing and numeric analysis implemented in the CoLiTec software. It includes inverse median filtration, calibration using the master frames, object detection, etc. Then the orbit parameters, like the right ascension and declination, were determined for a certain moment. After receiving the two observations of an investigated object at different times, the classic Väisälä method is applied. The created algorithm is implemented as a processing pipeline that contains a cooperation between the CoLiTec software pipeline and a special implemented plugin based on the general Väisälä algorithm. Such a plugin is realized as a console application based on the programming language Delphi. The created mathematical method was verified in practice based on the classical mathematical models and fuzzy clustering data arrays with omitted observations as well as statistical modeling [48]. With help of the developed processing pipeline, the several new SSOs (Main-belt asteroid 2017 AB8 (2014 OD380), Mars-crossing asteroid 2017 QX33, Main-belt asteroid 2017 RV12) were firstly discovered and some of the lost SSOs were found again during the astronomical observations at the Kyiv comet station and the Odesa-Mayaky observatory [49].

The further research will be conducted on processing newly created series of CCD frames with the astronomical SSOs by the new Lemur software of the Collection Light Technology (CoLiTec) project [50].

6. Acknowledgements

The research was supported by the Ukrainian project of fundamental scientific research “Development of computational methods for detecting objects with near-zero and locally constant motion by optical-electronic devices” #0124U000259 in 2024-2026 years.

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ОТРИМАННЯ ДАНИХ ПЕРВИННИХ ОРБІТ ОБ'ЄКТІВ СОНЯЧНОЇ СИСТЕМИ ЗА ДОПОМОГОЮ ПРОГРАМНОГО ЗАБЕЗПЕЧЕННЯ COLITEC ТА МЕТОДУ VÄISÄLÄ

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Анотація. *Розділ присвячено конвеєру обробки даних первинних орбіт і виявлення нових об'єктів Сонячної системи за допомогою програмного забезпечення CoLiTec і класичного методу Вяйсяля. Першим кроком такого конвеєра обробки є виконання послідовних астрономічних спостережень і класичного астрометричного редукування даних. Він реалізований як комбінація загальних математичних алгоритмів і методів обробки астрономічних кадрів, інкапсульованих у програмне забезпечення CoLiTec. Він містить зворотний медіанний фільтр, астрономічне калібрування з використанням калібрувальних майстер-кадрів (bias, dark, flat, dark-flat), виявлення астрономічних об'єктів і їх траєкторій у серії кадрів та інші дуже корисні та важливі функції. Після цього розраховуються особливі параметри орбіти об'єкта (пряме сходження і схилення) в певний час. Коли ми отримуємо принаймні два спостереження одного і того ж досліджуваного об'єкта в різні моменти, можна застосувати класичний алгоритм Вяйсяля. Для цього розраховується первинна орбіта з двох найближчих спостережень. Потім обчислюються геоцентричні прямокутні координати та відповідні геоцентричні компоненти швидкості. Це дає нам можливість визначати кеплерівські елементи орбіти досліджуваного об'єкта в будь-який час, який нас цікавить. Розроблений алгоритм реалізовано у вигляді конвеєра обробки, що включає комбінацію програмного забезпечення CoLiTec та створеного інструменту з інкапсуляцією методу Вяйсяля. Практично перевірено створений конвеєр обробки даних первинних орбіт і відкриття нових об'єктів Сонячної системи за допомогою програмного забезпечення CoLiTec і класичного методу Вяйсяля. З його допомогою вперше повідомляється про кілька нових астероїдів і знайдено кілька втрачених малих тіл Сонячної системи на Київській кометній станції та в обсерваторії Одеса – Маяки.*

Ключові слова: *Інтелектуальний аналіз даних, конвеєр обробки, астрономічні спостереження, програмне забезпечення CoLiTec, метод Вяйсяля, обробка зображень, калібрування зображення, астрометричне зменшення, фотометричне зменшення, виявлення об'єктів, позиційні координати, визначення орбіти, об'єкти Сонячної системи*