NEW ASTRONOMICAL IMAGE PROCESSING SOFTWARE - FIRST RESULTS OF USING

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ABSTRACT

Based on the client-server technology, a unified system named the Centralized Processing of Optical Sensors Data (CPOSD), was installed at the National Space Facilities Control and Test Center of State Space Agency of Ukraine (NSFCTC). Implementation of the system made it possible to obtain measurements in a “pseudo-real” time scale, i.e. 15-30 minutes (at some “average night quality”) after receiving the last image of separate sequences of frames from the telescope. This software allows the NSFCTC to process observations of artificial Earth satellites (including space debris) and Near-Earth Objects. The software development approach minimizes the observer's workload with details when processing large volumes of received images, because the main task is organizing and conducting observations (selection of objects and observation modes). Currently, an update is being prepared to add a function for generating ultra-precise light curves and visual control of data accuracy, with convenient display of graphs, the ability to delete measurements with significant errors, and save measurements in various formats. Also, a separate small server space is being prepared to open and available to anyone who wants to try this software.

The report will present the main features of using the CPOSD.

1. INTRODUCTION

The significant increase in artificial objects in near-Earth space, especially in the LEO and GEO regions, has significantly complicated space situational awareness (SSA) and space traffic management (STM) tasks. The increase in potential collisions increases the accuracy of positional measurements of objects that may collide and the speed of sending such information to analytical centers.

This situation leads to old software products that process optical observations, which do not always meet new requirements and challenges. One of the ways to resolve this contradiction is to develop and implement new, more effective software for processing optical observations of spacecrafts and space debris, as one of the components necessary for the successful solution of SSA and STM tasks.

In this report, we will talk about the new special software named Centralized Processing of Optical Sensors Data (CPOSD), which was purchased by the National Center Space Facilities Control and Test Center (NSFCTC) of the State Space Agency of Ukraine at the end of 2023. First, the features of CPOSD as a software product will be analyzed, then an overview will be provided of the results of using CPOSD by the optical sensors of the NSFCTC, after which possible ways to improve CPOSD further will be discussed.

2 FEATURES OF THE CPOSD’S PROGRAM IMPLEMENTATION

CPOSD is a unique software, which is an extension of the Lemur software [7], allows processing astronomical frames (in FITS format [6]) in an automated "streaming" mode (Fig. 1), namely:

- alignment of frames by brightness level;
- carrying out astrometric reduction of frames with the possibility of using different types of reduction equations: linear model (2x3 plate constants), cubic model (2x10 plate constants), fifth-degree model (2x21 plate constants);
- carrying out photometric reduction of frames;
- identification of stars in the frame with a reference star catalogue for any image variant (stars in the form of streaks or points) using star catalogue: UCAC5 or GAIA DR2;
- determining the estimated coordinates and brightness of non-stellar space objects (SO) for any image variant (SO in the form of a streak or point);
- determination of the estimated angular coordinates of the SO in the International Celestial Reference frame (ICRS);
- automatic detection of tracked SOs in LEO, MEO and GEO orbits;
- automatic detection of all SOs in the field of view (FoV) on MEO and GEO orbits;
- identification of the found SOs with the orbit catalogue in the Two Line Elements (TLE [5]) format (for example, the USSPACECOM catalog [8]);

Proc. 9th European Conference on Space Debris, Bonn, Germany, 1–4 April 2025, published by the ESA Space Debris Office
Editors: S. Lemmens, T. Flohrer & F. Schmitz, (http://conference.sdo.esoc.esa.int, April 2025)

• ability to edit personal and functional parameters of the software;

• display of the results of observations and processing on the monitor screen;

• visual analysis of moving objects (satellites, asteroids and comets) detected in an automated mode by the software;

• removing false objects (it is necessary to pay attention to previously unknown objects);

• manual measurement of objects (satellites, asteroids and comets) that were not detected in the automated mode;

• setting visualization parameters (brightness, contrast, palette...);

• working with the list of processed series, generating a report on the entire list of series;

• generating processing result files in the following formats: MPC1992, TELEGRAM, MEA and TDM (the latter according to the CCSDS 503.0-B-2 standard [9] in the part related to optical observations);

• creating and sending reports.

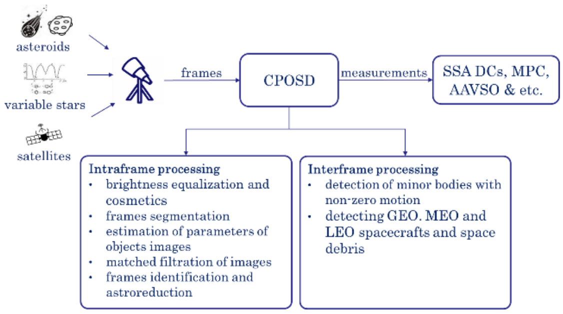


Figure 1. Generalized scheme for processing optical observation data using CPOSD.

The architecture of the CPOSD uses a client-server approach (Fig. 2). The server part is responsible for:

storing and managing all databases that are necessary for the operation of the CPOSD;

directly processing the received input data according to the corresponding configuration files;

information exchange from the server side.

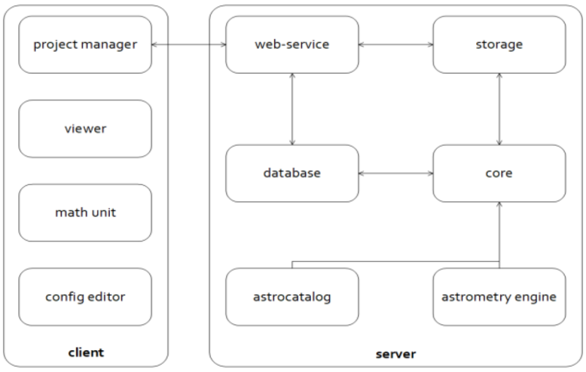


Figure 2. CPOSD's architecture.

The client part is installed on each optical sensor, and the data is planned to be processed using the CPOSD. It is responsible for:

information exchange from the client side;

creation, editing and storage of configuration files;

visual control of processing results, including removal of false objects and manual measurement of the SO;

generation of result files and reports.

System requirements for the client and server parts are given in Tab. 1.

Table 1. Main system requirements for CPOSD.

Server part	
Server CPU of Intel Xeon type	No less than 10 cores
RAM	No less than 2 GB for each core
HDD (SSD)	No less 1 TB
OS	ubuntu 18.04, x64
Other supporting software	GNU C++ toolchain, git, PostgreSQL, OpenJDK, FFmpeg, python 3, Lazarus
Client part	
CPU	Intel(R) Xeon(R) W-2133 CPU @ 3.60GHz or better
RAM	No less than 16 GB
OS	Windows 10 or higher (x64)

The main advantages of the client-server architecture are:

a significant reduction in system requirements for the hardware of the client system (all complex computing operations are performed on the server; all large databases are also located on the server);

easy updating of the software computing core and correction of detected errors (only on the server);

simplified increase in computing power (it is enough to allocate more resources to the server part).

At the same time, this type of architecture also has system shortcomings that cannot be eliminated:

the need for stable communication between the client and server parts imposes additional requirements for the reliability of network connections;

a failure of the server part makes it impossible to process data from all client parts.

3 RESULTS OF USE

3.1 Optical sensors of the NSFCTC use the CPOSD

The client parts of the CPOSD (according to the purchased license) were installed on three new optical sensors of the NSFCTC.

3.1.1 Telescope type 1 (optical-electronic observation station)

Telescope type 1 (optical-electronic observation station) (OES50) commissioned in 2019 (Fig. 3).

Figure 3. OES50.

The main specifications of OES50 are given in Tab. 2.

Table 2. The main specifications of OES50 [2].

Aperture, cm	50
Focal length, m	1.9
Camera	Wide FoV (WFoV): FLI ML 16070 Narrow FoV (NFoV): QHY-174M GPS
Chip size, pix.	WFoV camera:4864 x 3232 NFoV camera: 1936x1216
Pixel size, μm	WFoV camera: 7.4 NFoV camera: 5.86
Scale without binnig ("/pix.)	WFoV camera: 0.80 NFoV camera: 0.64
FoV (deg^2)	WFoV camera: 0.774 (64.8'x43') NFoV camera: 0.075 (20.7'x13')
Mount	Equatorial fork
Max slew speed, deg/s	Up to 5.0

Currently, OES50 uses only the CPOSD to process frames obtained by the WFoV camera.

3.1.2 Optical-electronic observation station «Novosilki» (telescope type 2)

Optical-electronic observation station **«Novosilki» (telescope type 2)** (OES30) (Fig. 4) commissioned in 2019.

The main component of OES30 is the WSZ-300 super-fast telescope on a WSF-320WD modified German equatorial mount with direct drive. It is equipped with two cameras: FLI ML16070 and QHY-174M GPS, one of which is mounted on the telescope. The main specifications of the telescope with each camera are given in Tab. 3. The CPOSD was used to process the frames obtained using the QHY-174M GPS camera.

Figure 4. View of the OES30 telescope.

Table 3. The main specifications of OES30 [2].

Aperture, cm	30
Focal length, m	0.3
Camera	1 camera: QHY-174M GPS 2 camera: FLI ML 16070
Chip size, pix.	1 camera: 1936x1216 2 camera: 4864 x 3232
Pixel size, μm	1 camera: 5.86 2 camera: 7.4
Scale without binnig ("/pix.)	1 camera: 4.01 2 camera: 5.1
FoV (deg^2)	1 camera: 2.89 (130'x80') 2 camera: ~31.74 (6.9°x4.6°)
Mount	modified German with direct drive
Max slew speed, deg/s	Up to 10

3.1.3 Optical-electronic observation station (telescope type 3)

Optical-electronic observation station (telescope type 3) (OES35) (Fig. 5), commissioned in 2022, consists of two tubes (35-cm Hamilton and 25 cm Maksutov-Cassegraine) on one mount. The main specifications of the telescope are given in Tab. 4.

Figure 5. OES35.

Table 4. The main specifications of OES35 [1].

Hamilton tube	
Aperture, cm	35
Focal length, m	0.7
Camera	QHY-174M GPS
Chip size, pix.	1936x1216
Pixel size, μm	5.86
Scale without binnig ("/pix.)	1.7
FoV (deg^2)	0.53 (55'x35')
Maksutov tube	
Aperture, cm	25
Focal length, m	3.4
Camera	QHY-174M GPS
Chip size, pix.	1936x1216
Pixel size, μm	5.86
Scale without binnig ("/pix.)	0.36
FoV (deg^2)	0.03(13'x8')
Mount	
Type	Equatorial
Max slew speed, deg/s	Up to 20

3.2 Results of the CPOSD use

3.2.1 General application results

One of the main results of using the CPOSD is a significant increase in optical observation data processing efficiency. The results of processing observations obtained for one LEO pass of the SO can be ready within 15–30 minutes after receiving the last frame (if the total number of frames does not exceed 300–500). Measurement files in a specified format for the entire night of observations can be obtained 1.5–2 hours after the end of observations (provided that each pass was not analyzed separately during the observations). This became possible by organizing the processing of observations in real time and automatically detecting and identifying SOs on a series of frames, which significantly reduces the observer's work in checking the processing results and creating measurement files (Fig. 7).

It is also worth noting that the reduction in the number of unprocessed frames and frames with false star identification led to obtaining a significant number of measurements with large errors. The overall accuracy of astrometric measurements corresponds to the accuracy of other software pipelines, such as the Polish PSST [7].

Improving the measurements' quality allowed successful participation in international observation campaigns and observations under individual international agreements (see below).

3.2.2 Participation of NSFCTC's optical sensors in the campaign to support the re-entry of the CLUSTER 2/FM6 spacecraft

The campaign was organized by the European Space Agency (ESA) and was conducted from May to September 2024 [4]. Three optical sensors of the NSFCTC participated in the campaign: OES50, OES30, OES35. The first observations of the spacecraft were obtained on 11.05.2024, and the last on 08.09.2024, approximately half an hour before the spacecraft entered the dense layers of the atmosphere. The processing of optical observation data obtained within the framework of the campaign was carried out using the CPOSD.

At the same time, the capabilities of the CPOSD allowed for successful participation in the campaign even in the last days, when the requirements for the promptness of sending the obtained measurements to ESA, which conducted a general analysis of all observations and their further use to refine the parameters of the spacecraft orbit, increased significantly. Some difficulties arose due to the inability to filter the obtained measurements more to identify potential errors.

The average accuracy of observations obtained by the optical instruments of the NSFCTC during the campaign is shown in Tab. 6-7.

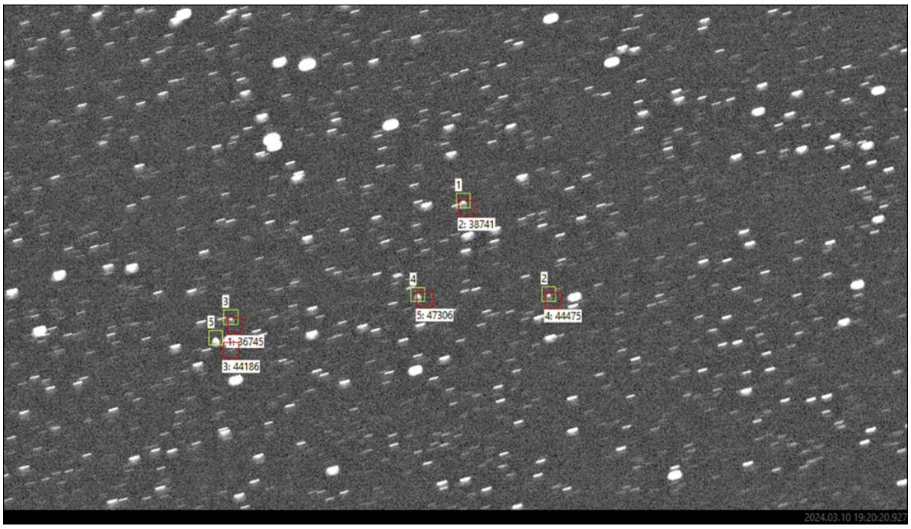
The quality and efficiency of obtaining observations by the optical sensors of the NSFCTC fully satisfied the ESA specialists, as evidenced by the letter of gratitude received from them. It should be noted that the optical sensors of the NSFCTC had the smallest telescope aperture sizes among all the instruments that officially participated in the campaign and provided their measurements.

3.2.3 Results of calibration of NSFCTC's optical sensors by the Polish Space Agency

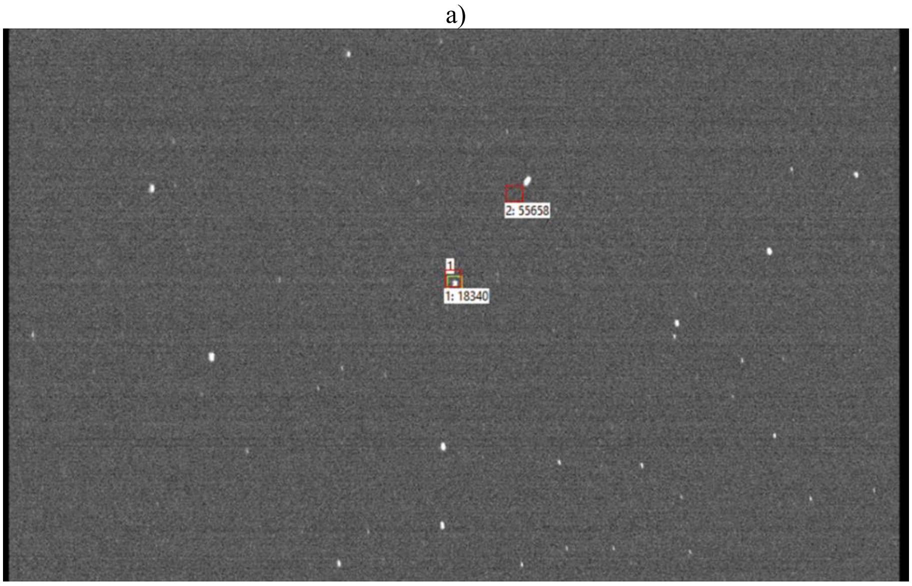
In October 2024, an agreement was concluded between the Polish Space Agency (PolSA) and the NSFCTC on providing PolSA with optical observation data (according to a defined list) obtained by the NSFCTC. One of the points of this agreement was the conduct of calibration observations to assess the potential quality of the data that can be obtained.

carried out on OES35, which affected the results of calibration observations in 2022.

Active satellites of the European navigation system GALILEO were selected as reference satellites for calibration observations. All NSFCTC optical sensors participated in the calibration observations. The processing of optical observation data obtained within the campaign was done using the CPOSD. Similar calibration observations were carried out in 2022 before the CPOSD was used. A comparison of the accuracy estimates of calibration observations made by PolSA specialists for the campaigns in 2022 and 2024 is given in Tab. 8. It can be seen that for two sensors (OES50 and OES30) the calibration results have improved significantly, while for OES35 they have remained almost identical. This is explained by the fact that in 2022, tests of the prototype of the CPOSD were already



a)



b)

Figure 7. Examples of the CPOSD work results: a) Identification of the group of SOs on GEO; b) Identification of SOs on LEO.

Table 6. *Precision of NSFCTC's optical sensors measurements according to ESA data*.

Sensor	Aperture, cm	Scale, "/pix	RMS,"			
			RA[1]	Dec[2]	AT[3]	CT[4]
OES50	50	1.7	1.28	0.76	1.28	0.59
OES30	30	4.0	1.85	3.01	1.96	2.89
OES35	35	1.7	1.9	2.35	1.75	2.31

[1] – Right Ascension;
[2] - Declination;
[3] – along track;
[4] – cross track.

Table 7. Precision of NSFCTC's optical sensors measurements according to ESA data (last three days of observations).

Sensor	Aperture, cm	Scale, "/pix	RMS,"			
			RA	Dec	AT	CT
OES50[1]	50	1.7	0.32	0.14	0.31	0.12
OES30	30	4.0	1.13	1.16	1.35	1.13
OES35	35	1.7	1.55	1.11	1.777	0.77

[1] – Only one track 06.09.2024.

Table 8. Comparison of the results of calibration observations of the NSFCTC's optical sensors in 2022 and 2024 (data provided by PolSA).

Year of observations	Number of tracks	Of these, anomalous (RMS of errors more significant than the image scale)	Max./min RMS of errors in tracks
OES50			
2022	5	1	708.69/0.57
2024	9	0	1.09/0.21
OES30			
2022	9	2	159790.29/1.39
2024	9	1	5.69/0.69
OES35			
2022	7	1	2.00/0.36
2024	8	1	2.56/0.31

4. FUTURE PLANS

The following ways of improving the CPOSD can be proposed based on the above.

1. Further improvement of computational methods for automatic SOs detection and identification with the current orbit catalogue.

2. Improvement of methods for obtaining photometric information. It is advisable to create the possibility of obtaining estimates of the apparent brightness of a SO in stellar magnitudes from the determined values of its instrumental brightness on all received frames of the series, and not only on those identified with the stellar catalogue by analogy with [3]. This can be designed as a separate software module or a program component to verify the result visually.

3. Creation of a module to check the internal and external (for SOs identified with the catalogue) accuracy of the obtained positional measurements with the ability to filter measurements with anomalous errors. The module can be part of the program for visual verification of processing results or designed as a separate auxiliary program. The first version of such a separate LookPlot module (Fig. 8) is already undergoing verification. It provides the ability to estimate the errors of positional measurements relative to the TLE propagation, filter out outliers, and assess the quality of the obtained photometric data. In addition, this module allows you to significantly simplify the saving of processing results in the selected format, including TDM.

4. Increasing the program's speed for visually verifying processing results when working with many frames/detected SOs.

5. Adding to the program for visual verification of results is the ability to combine individual detected tracks into one, both at the stage of verification of processing results, and during the creation of measurement files.

6. Adding to the server part of the CPOSD functions to check the amount of free disk space remaining with a warning about its exhaustion.

7. When expanding the network of NSFCTC's optical sensors, it is advisable to continue processing all optical measurements with the CPOSD by purchasing appropriate licenses for each sensor and expanding the technical characteristics of the server.

5. CONCLUSION

1. The use of the CPOSD has significantly increased both the accuracy of positional observations obtained by the optical sensors of the NSFCTC and the speed of their acquisition. The high quality of measurements obtained using the CPOSD has been confirmed during the participation of the NSFCTCs optical sensors in international observation campaigns.

2. It is advisable to focus further on improving computational methods for detecting and identifying SOs, increasing the accuracy of photometric data, improving existing and creating new tools for

controlling the results of processing optical observation data. This will improve the quality of the measurements and increase the convenience of using the CPOSD.

3. For broader testing, the possibility of involving interested SSA operators and astronomy enthusiasts, an open service has been created to search for space objects in a series of astronomical frames, all the details of which can be found here: "https://colitec.space".

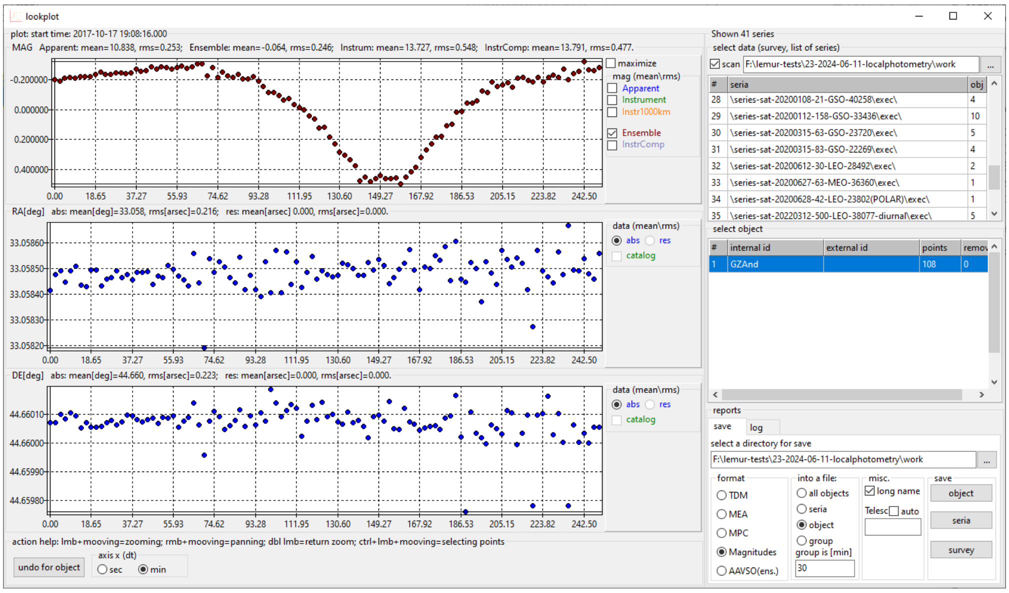


Figure 8. View of the LookPlot module with loaded processing results from one of the observation nights.

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