

# DEVELOPMENT OF A REAL-TIME MONITORING SYSTEM FOR SPACE OBJECTS

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## ABSTRACT

*This paper presents the results of the SKEYE contract 03 PSCD/2022, financed through the Sectorial Research and Development Plan of the Romanian Ministry of National Defence. The project involves the development of a Space Situational Awareness (SSA) Space Operations Centre (SPOC) together with related sensors: Robotic Astronomical observatory; quad band spectrum monitoring antenna system (X, Ku, Ka and Q bands) and GNSS spectrum monitoring network. Sensors are remotely controlled from SPOC via dedicated software platform. Moreover, at SPOC level, operational scenarios can be simulated using a dedicated software platform – AGI STK. This paper explores the system's implementation, benefits and security implications.*

**KEYWORDS:** defense, GNSS, operation centre, RF monitoring, SST

## 1. Introduction

With the increasing number of space applications and missions, the number of stakeholders grows as years go by. Even

though Romania is not yet one of the major actors in this sector, space situational awareness is very important for ground operations planning. The Skeye system

covers real time monitoring of the GNSS spectrum via a wide area network of sensors, real time tracking and survey for LEO, MEO and GEO satellites using a ground optical system and RF spectrum monitoring in X, Ku, Ka, Q bands for signal emitted by GEO satellites.

The SkEye project aims to create a new system that enables the National Ministry of Defense to manage and survey the security of GNSS, radio frequency and space surveillance and tracking by integrating them into a single space operations centre. This paper examines the system's implementation, benefits, and security implications.

The SkEye project is implemented by a consortium led by the Romanian Space Agency (ROSA) having the role of project coordination and management. Consortium partners are:

- **Astronomical Institute of the Romanian Academy** – being in charge with Space Surveillance and Tracking

(SST) software development and system testing,

- **Romanian InSpace Engineering SRL** – being in charge with the system development, integration and testing,

- **Institute of Space Sciences** – being in charge with the STK operational scenarios and offering support for system integration

## 2. General Aspects of the Skeye System

This project aims to address uniformly the requirements defined by the terms of reference starting from the development of the main components: SST, GNSS monitoring and radio spectrum monitoring and continuing through integrating them into a SpOC – Space Operation Centre. The key characteristics of the system are enumerated in this section.

System block diagram is presented in the image above (see Figure no. 1).

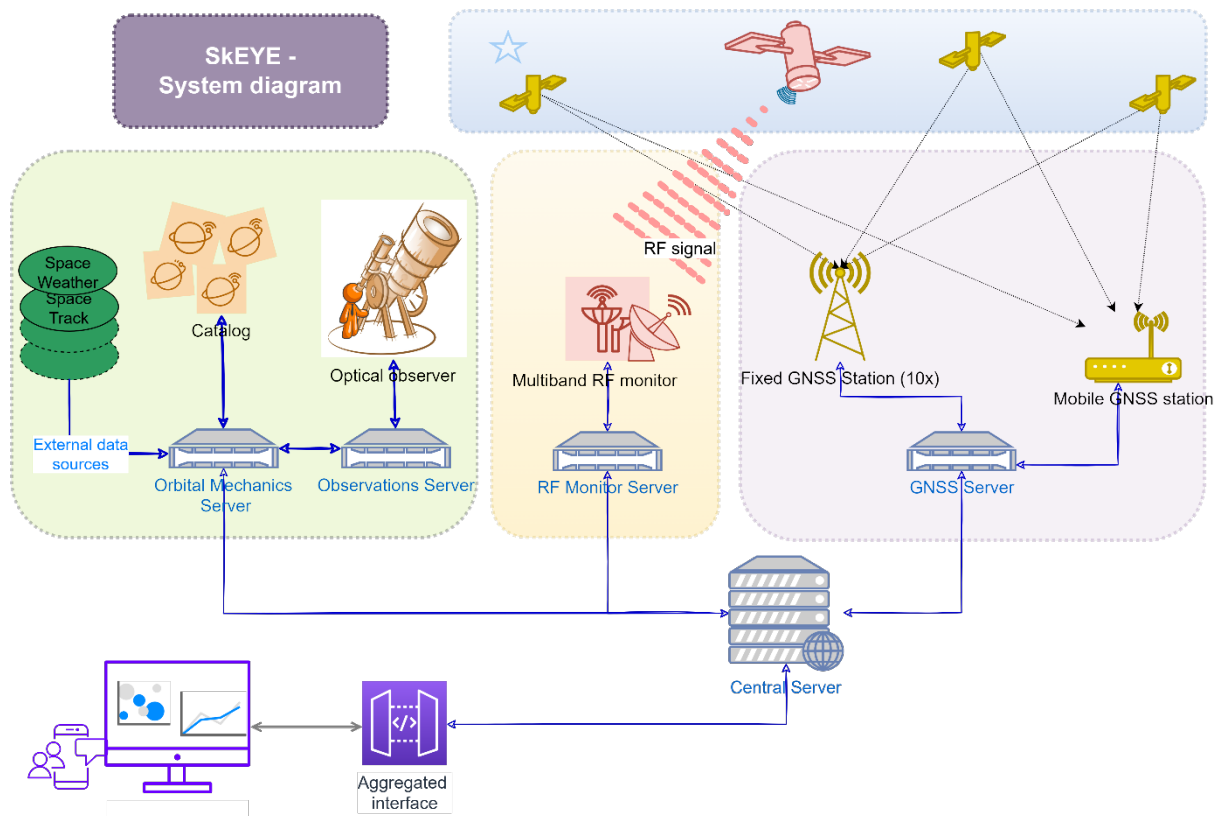


Figure no. 1: System diagram of the project

## 2.1. GNSS Signal Monitoring System

The main role of the signal quality monitoring system is to monitor the GNSS spectrum and provide real-time information about the status of the GNSS signal regardless of the constellation that is providing it at that time, and to provide the operator with an overview of the quality and availability of this signal. This means that any jamming or interference on the signal can be identified and signalled in the operator interface by graphic signs and changing some parameters in the interface of the GNSS service. Thus, the GNSS signal quality monitoring system is composed of three major components:

- Ten fixed GNSS monitoring stations (availability and integrity of the GNSS signal, as well as identification of jamming or interference).

- A mobile station for locating detected interference.

- A GNSS service, as an integral part of the SPOC operational centre, with the role of centralising fixed station information.

Each of the ten fixed stations has a control unit, and a professional multi-frequency, multi-constellation GNSS antenna, while the mobile station has a control unit and five GNSS antennas linked to five GNSS receivers.

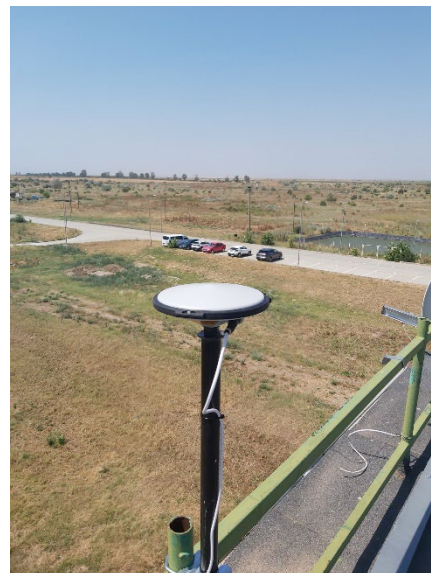


Figure no. 2: Configuration of the fixed GNSS monitoring station (the control unit – left side; the GNSS antenna – right side)

These stations provide real time GNSS spectrum monitoring to alert the user when interferences are encountered. The software is built on a containerized infrastructure to ensure scalability, station encapsulation and modularity. By employing this architecture, it facilitates firmware updates since the only necessary operation needed is to upgrade the deployed image version.

It is essential to have centralized control over containers that allows for

starting, migrating, and terminating services. Furthermore, orchestration makes it possible to establish and guarantee service policies and permissions across the various layers of architecture. Thus, orchestration can be utilized by both developers and operations for agile service development, integration, and implementation, to enhance security, and even to plan updates and tasks across layers (Rufino et al., 2017).

The GNSS module is a web microservice based on RESTful (Representational State Transfer) architecture. RESTful architectural style emphasizes the scalability of interactions between components, uniform interfaces, independent implementation of components and creation of a layered architecture to facilitate caching of components to educate them user-perceived latency, enforce security and encapsulate legacy systems.

The two main software modules of the GNSS service are the realtime interference monitoring module and the GNSS performance reporting module. They use data collected by fixed stations and a mobile station to provide the user, through the web interface (see Figure no. 3,

Figure no. 4), information about the GNSS signal quality at the fixed station level and interference events detected. Information on the direction of the source of interference will be obtained with the help of the mobile station.

The *GNSS Performance Reporting Software Module* generates a report in which the performance of the GNSS system is analyzed for a period of 14 days. Following the execution of the processing chain, a series of performance parameters (positioning accuracy, availability, continuity and integrity of the system) are generated every 2 weeks. Figure no. 3 consists of multiple bar charts representing positioning accuracy metrics for different GNSS systems over the course of 14 days.

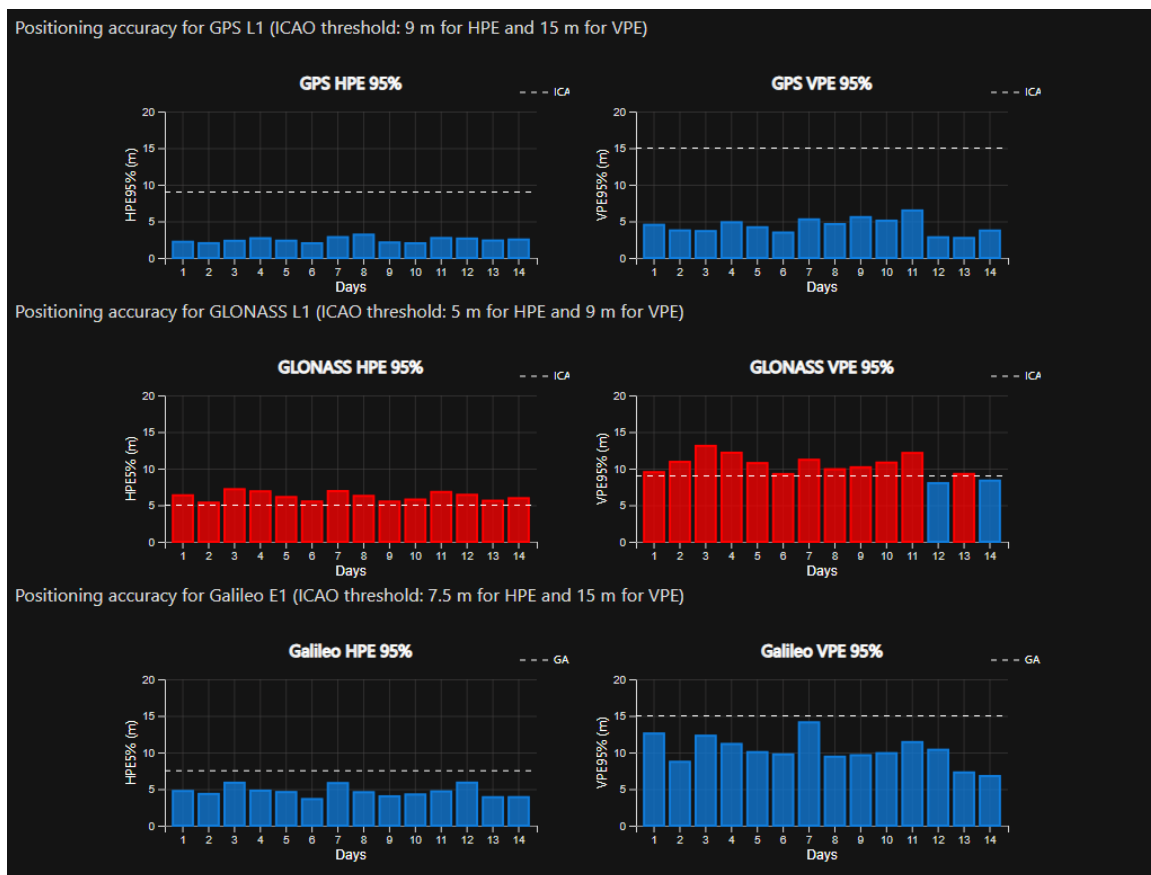


Figure no. 3: Snapshot from the “GNSS Performance Report” page  
(Position Accuracy chapter)

The *Realtime Reporting Software Module* performs two major roles: it detects in realtime interferences and at the same

time it computes horizontal and vertical positioning errors (HPE and VPE indicators) for the GNSS system.

The service then sends the results via a RESTful API to the module behind the system. The module publishes data in the topics to achieve asynchronous communication with the frontend module. The service stores the processed data in a database.

Through the frontend module, users are able to receive interference data in real time. This type of reporting provides immediate information about any detected interference (see Figure no. 4).

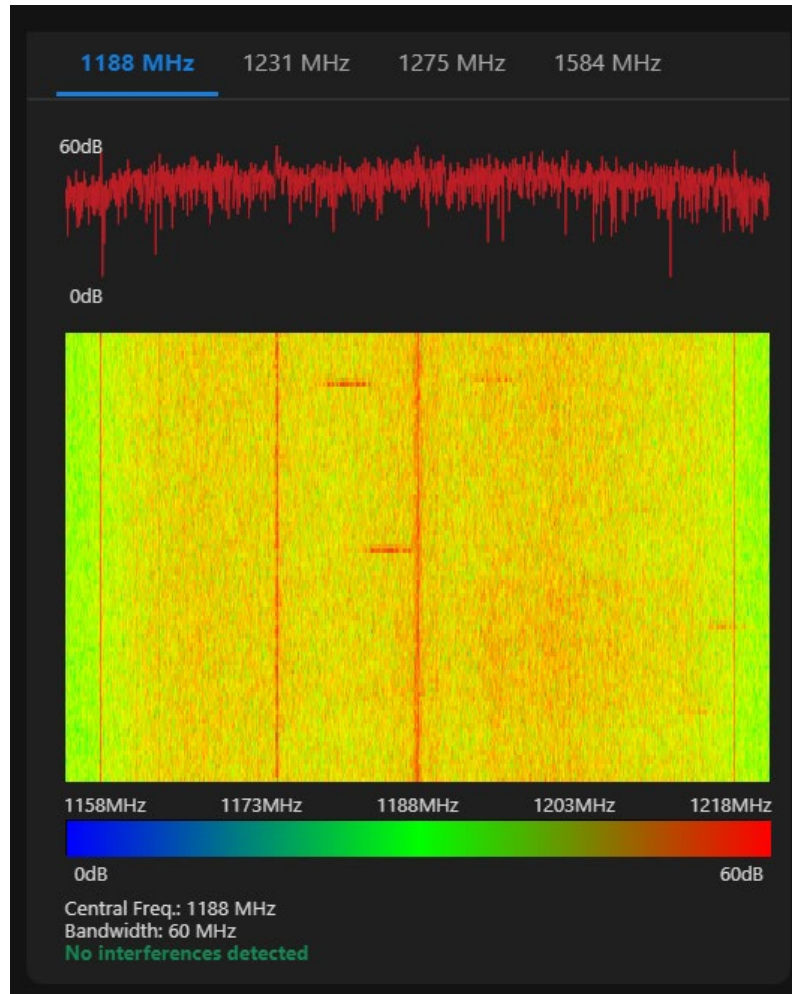


Figure no. 4: Snapshot from the “GNSS Spectrum” page

## 2.2. Radio Frequency Monitoring System

The X, Ku, Ka, and Q band radio frequency monitoring system for geostationary satellites is an advanced and specialized solution designed to ensure accurate and efficient surveillance of the radio spectrum used in satellite communications. This complex system integrates state-of-the-art technologies to detect, analyze and manage radio signals

emitted by geostationary satellites. The system is comprised of four main modules:

- Signal acquisition module
  - Radio receiver sub-module
  - Measurement calibration sub-module
- Antenna positioning module
- Command and control module
- Software module – a SMR service integrated in SpOC that merges the data provided by the spectrum analyzer.





Figure no. 5: *Radio frequency monitoring system*

The fully robotic system is remotely controlled from SPOC.

### ***2.3. Space Surveillance and Tracking (SST) System***

On a global scale, the standard on monitoring resident space objects is given by the USA through the Space Surveillance Network. In the EU, this mission is

coordinated by EUSST, which is a multinational consortium that includes Romania among its members.

The custom developed robotic astronomical observatory was designed to be remotely operated. It integrates the image processing chain, so it is able to directly provide the track data message file (TDM) to the SPOC.

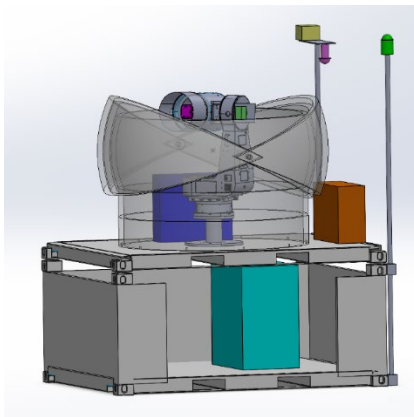


Figure no. 6: *Space Surveillance and Tracking (SST) system*

The robotic astronomical observatory comprises the following subsystems:

- Mechanical structure.
- Robotic dome
- Electro-optical sensor
- Server for data processing
- Monitoring system for weather/astronomical conditions
- System for security surveillance
- The air conditioning system

The worldwide state of the art system meets high performance quality indicators regarding the data volume and availability. The system provides astronomical data that has an average noise level of 0.7 arcseconds. With a spatial resolution of 1.94 arcsec/pixel and an ultra-wide field of view of 8 x 6 degrees, the observatory is able to

perform both surveillance and tracking for LEO, MEO and GEO objects. The system's characteristics allow also tracking and monitoring the potential dangerous small Solar System natural objects (NEO) that passes through Earth's proximity (asteroids, comets). The all-sky camera installed in the astronomical observatory is a very useful equipment that helps the operators to evaluate the sky quality on the site. It can also be integrated into worldwide networks dedicated to track the incoming meteoroids into the Earth's atmosphere.

The SST system has the potential to be further integrated into international networks and contribute to valuable data exchange with strategic partners.

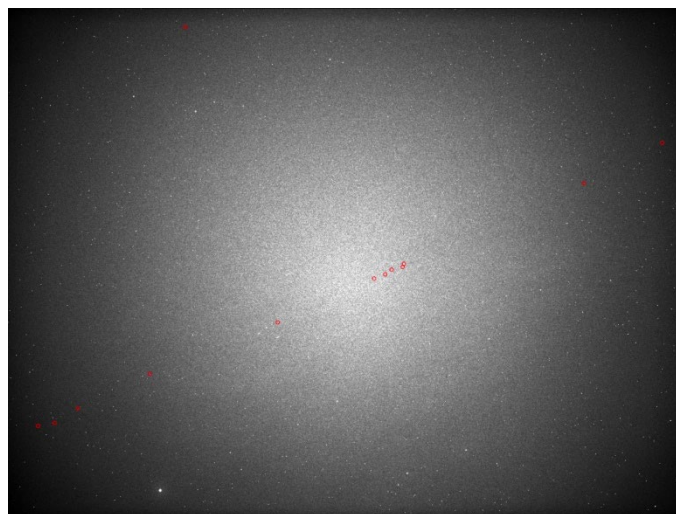


Figure no. 7: *13 Geostationary satellites discovered in a single image (10deg field diagonal). Red circles represent the satellites from the geostationary ring*

## 2.4. Space Operations Center (SpOC)

The SpOC module's main role is to orchestrate the chain of communication between various subsystems (SST observer,

GNSS monitoring and monitoring of the geostationary origin radio spectrum).

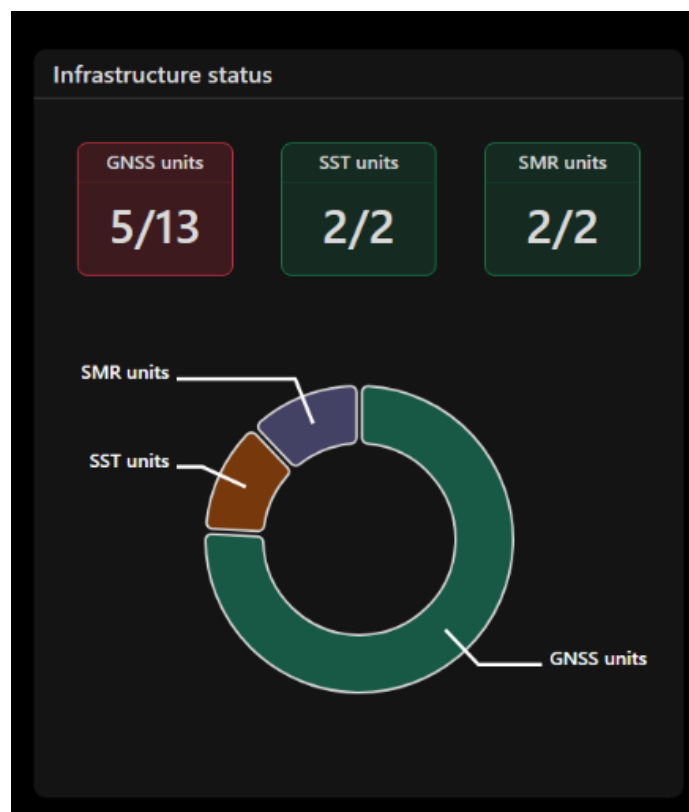


Figure no. 8: *Infrastructure status presented in the SpOC Interface*

The SPOC system is implemented as an application programming interface (API) which allows communication between subsystems using the HTTP protocol. Access to subsystems is secured by token-based authentication protocols (tokens).

The SPOC operational centre is composed of the following major components:

- Graphical user interface (GUI), which provides the user with control and monitoring actions for SMR, SST and GNSS subsystems

- API Gateway, which functions as a reverse proxy to manage client requests to one or more backend services

- Message broker, which has the role of receiving the data flows from the

components GNSS, SMR and SST and redirecting them in real time to the graphical interface

- Authorization server, which is designed to authenticate and authorize users

Each of the three major components of the system has a dedicated blade server. Therefore, there are dedicated servers for:

- the surveillance and tracking system of artificial objects in space,

- the GNSS signal quality monitoring system and

- the radio spectrum monitoring system of geostationary origin.

These servers have similar features, but they differ in their ability to process, store and send data to SPOC depending on the specifics of each component.



### 3. Conclusions

As the space industry is becoming critical to all domains, the SkEye project addresses the necessity for a dedicated centre to monitor and improve the performance of both RF communications and GNSS signals by providing a comprehensive solution for ensuring operational quality and maintaining a reliable infrastructure for future missions. It operates across three key domains: RF communications, GNSS signal quality, and space surveillance and tracking, all managed from a centralized space operations centre.

SkEye enhances space situational awareness (SSA), supports defence operations, and strengthens Romania's capability to monitor the electromagnetic spectrum. Designed with a modular architecture, the system can be easily adapted or expanded by integrating

additional instrumentation as needed. This flexibility ensures that SkEye system can remain at the forefront of technological advancements through continuous updates, that can provide the means for effective and timely responses to the evolving security and operational challenges.

### Acknowledgment

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### REFERENCES

- Rufino, J., Alam, M., Ferreira, J., Rehman, A., & Tsang, K.F. (2017). Orchestration of Containerized Microservices for IIoT using Docker. *IEEE International Conference on Industrial Technology (ICIT)*, 1532-1536. DOI: 10.1109/ICIT.2017.7915594.
- Teunissen, P., & Montenbruck, O. (2017). *Springer Handbook of Global Navigation Satellite Systems*. Springer International Publishing.
- Sanz Subirana, J., Juan Zornoza, J.M., & Hernández-Pajares, M. (2013). *GNSS DATA PROCESSING, Vol. I: Fundamentals and Algorithms*. ESA Communications.
- Sanz Subirana, J., Juan Zornoza, J.M., & Hernández-Pajares, M. (2013). *GNSS DATA PROCESSING, Vol. II: Laboratory Exercises*. ESA Communications.