GeoTracker - a worldwide optical network for Space Situational Awareness

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ABSTRACT

With the continuous growth of space applications, the number of objects in orbit is increasing dramatically. Space Situational Awareness has become a necessity to insure safe operation of space assets.

Since 2008 Airbus Safran Launchers has been developing capabilities for Space Surveillance and Tracking.

Up to 2017, a network of optical stations with world-wide coverage has been deployed and is now fully operational. It performs tracking of objects in GEO/MEO/LEO orbits and provides optical angular measurements allowing orbit determination and feeding Airbus Safran Launchers' own catalogue of space objects.

This catalogue allows the provision of collision warning. Orbit refinement can then be performed on demand through the network.

With this Optical sensor network, Airbus Safran Launchers has the capability to provide data or services to government and private sector operational users of space assets.

This paper describes the system architecture, station design, performances and possible capabilities in the context of space debris.

1 NETWORK ARCHITECTURE

Airbus Safran Launchers GeoTracker network is based on several optical stations installed in observatories around the world. The locations of the stations were chosen in order to cover at least 90% of the geostationary belt, with comfortable redundancies on certain zones (for example, 3 sensors can cover the European zone).

The position of the stations and their associated coverage are given on the figure below.

Figure 1. Airbus Safran Launchers Geotracker Network - station location and coverage

An additional station with two instruments will be deployed on the African continent by the end of 2017.

Each station is connected to its own command and control (C2) system, physically collocated in an electronic bay. It is in charge of managing all the hardware elements of the sensor.

A datacenter located in Airbus Safran Launchers premises at Les Mureaux (France) manages all the sensors and the observations. It includes an orbit determination software and a web interface allowing planning of requests and access to measurements and orbit catalogues.

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2 OPTICAL STATIONS

2.1 Station concept

All the stations are robotized and can be used autonomously with no human in the loop. At the beginning of night, if requests have been sent to the station, the C2 performs the wake-up of the system, which includes the powering of the mount, telescope and camera, the opening of the shelter, the temperature setting of the camera and dark frame acquisitions (when necessary, for calibration purposes).

Then the observations are performed according to the requests received, the C2 is in charge of positioning the mount and acquire images. The image processing is performed locally, so that only processed data are to be transferred. This architecture drastically lowers the required bandwidth and allows the deployment of sensors in remote locations with limited Internet access. Images remain stored locally for a few months and can be downloaded for investigations if needed through the web interface.

During the observations, the weather is monitored thanks to a weather station. In case of rain/snow or strong wind, the observations are interrupted and the shelter is closed in order to protect the sensor.

After the last observation, the sensor is powered off and the shelter closed. On some stations, Airbus Safran Launchers built his own shelter, which is then fully controlled by the C2. In some other cases, the shelter is shared with other instruments. The C2 then only gets the roof status (open/close) in order to manage the observations.

2.2 Software architecture

3 main software components are running on the station computer:

- The web application: this interface allows operating the sensor in standalone mode with a web browser. It also exposes a REST API that is used for communication with the datacentre or to automate actions with scripts.
- The C2 module: this component is in charge of managing the hardware and executing the observation requests. It is highly configurable to adapt to all the different sensor configurations.
- The image processing software is executed at the end of each observation to generate the raw measurements from the images.

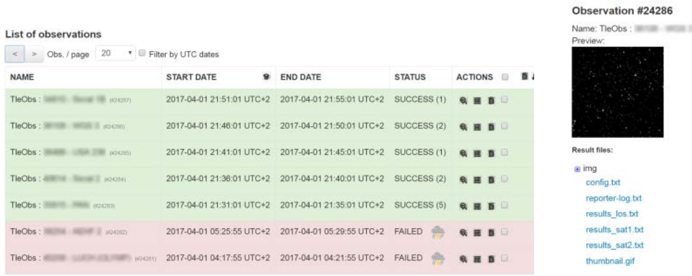

Figure 2. Web interface of a sensor

Remote access to a sensor is protected by SSH, firewalls, and OAuth2 for user authentication at the web application level.

2.3 Types of stations

There are two different kinds of stations:

- Tracking station, designed to follow orbital objects, given an a priori orbit.
- Survey station, designed to perform surveillance of a large sky zone.

The specificities of these stations are detailed in the following chapters.

2.3.1 Tracking station

A tracking sensor is designed to follow orbital objects, which means that:

- The FOV shall be sized so that it is bigger than the addition of designation and pointing accuracy
- The mount shall be fast enough to follow objects of interest.

The tracking instruments are then designed to have field-of-views (FOV) around 1-2 degrees, and high performance mounts (in terms of speed and tracking accuracy). Airbus Safran Launchers has three types of tracking sensors that are described in the following table.

	Diameter	FOV	Stations
Type 1	30 cm	2.4°	France 1
Type 2	50 cm	1.5°	Spain
Type 3	28 cm	1.55°	Australia (x2), Chile, France 2

Figure 3. Type 1 tracking station at Observatoire de la Côte d'Azur (OCA - France) – This sensor is dedicated to research and development (R&D) activities.

The image processing chain ensures the detection of tracked objects amongst an image set. All plots of the image are extracted and classified as object or star. The coordinates of all the objects in the field-of-view are given in CCD frame and in equatorial and altazimuthal coordinates relatively to the station position. The coordinates of the line-of-sight (centre of the image) are also computed, which can be useful for calibration purposes. An image-by-image estimation of the restitution accuracy can be provided. The result files consist in a table of date/time and coordinates for each object detected and can be used to feed orbit determination algorithms.

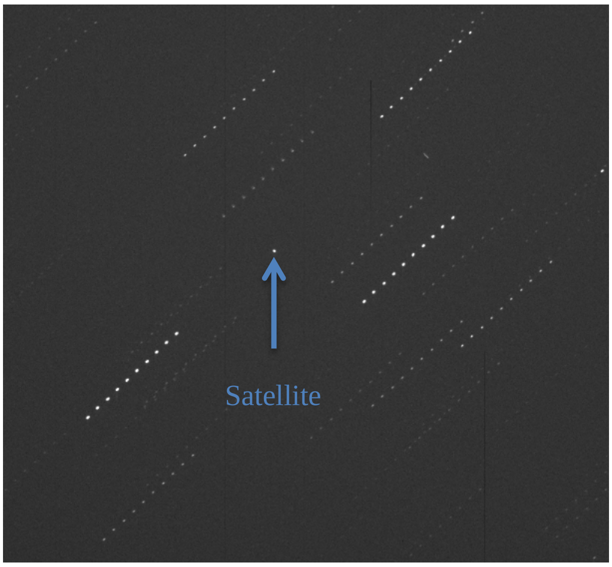

Figure 4. Cumulative image of 10 individual images showing moving stars and one GEO satellite

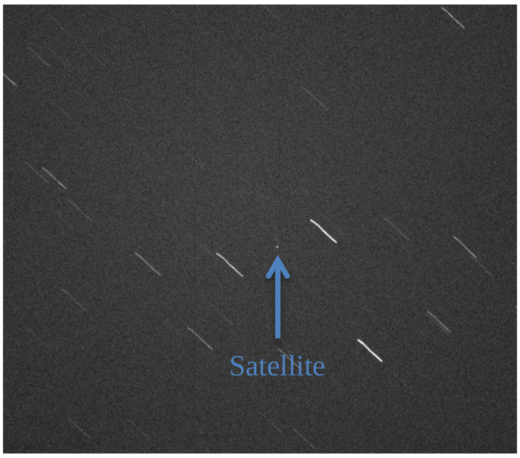

Figure 5. Example of LEO tracking image

The brightness of the satellite is also estimated thanks to photometric measurements relatively to the stars in the field-of-view (their own magnitude being known through the star catalogue). This can be useful for identification purposes.

2.3.2 Survey station

A survey sensor is designed to perform surveillance of a large sky zone. In order to ensure the best coverage, we shall choose the largest possible FOV. The pointing system is less constrained, because the requirements on the pointing accuracy and tracking velocity of the mount are much lower than for a tracking sensor. The main interest here is to observe lower orbits, which means that sensitivity constraints are lower and we can choose smaller optics diameter.

The chosen design is a double optics instrument allowing covering twice 16°x24°, as shown on the image below. It is mounted on a simple mount with basic pointing performances. The optics are aligned so that the individual field-of-views are slightly covering each other.

Figure 6. Survey sensor

	Diameter	FOV	Stations
Survey station	2x8cm	2x (16°x24°)	Australia (x2), Chile, South Africa (end 2017)

3 DATACENTER

The datacenter is in charge of the planning of the sensors and the management of the data produced.

It includes:

- An automated connection to external database
- A scheduler algorithm, to compute and optimize the planning of the observations
- A database filled up with the results of every observations performed on the sensors
- A correlation algorithm in order to identify observed objects with respect to external database and/or Airbus Safran Launchers catalogue
- An orbit determination algorithm for GEO objects, that automatically processes the data retrieved from the sensors when available
- A visualizer to plot the orbit data on 2D or 3D maps.

3.1 Scheduler

A scheduler is integrated in the datacenter to help the users with the planning of their observations. The scheduler is able to consider high level requests such as:

- TLE tracking with pattern:

  The scheduler allows the user to observe space objects considering several observations of the same object in the same night following a specific strategy (for example, N slots of X minutes). These observations will then be automatically planned by the scheduler with respect to the strategy.

- Longitude Scan:

  The longitude scan requests allow the user to ask for an observation of a specific part of the GEO belt (ex: from longitude -30° to +40°). Then the scheduler will automatically compute the pointing directions to be sent to the sensor in order to observe this part.

- Latitude scan:

  The latitude scan requests allow the user to ask for an observation of a specific GEO slot considering several inclinations (ex: from latitude -15° to +15° at longitude 130°). Then the scheduler will automatically compute the pointing directions to be sent to the sensor.

Besides, for each request the scheduler is in charge of computing the visibility period considering a set of constraints (phase angle, Earth shadow, minimum elevation, Moon, etc). Then the scheduler computes automatically the observation plan to be sent to the sensor by optimizing the concatenation of all the requests. It provides the user a list of scheduled and unscheduled requests.

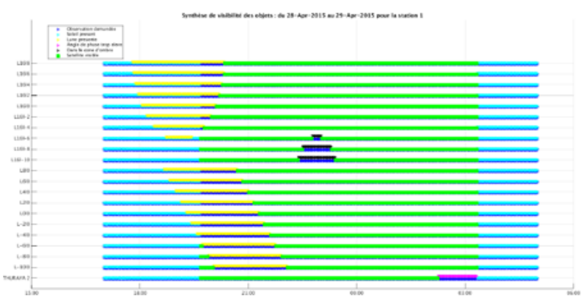

Figure 7. Example of visibility graph for several satellites - Constraints are represented as different colors, visibility periods are represented in green.

Specific exclusion periods can also be taken into account for expected maintenance periods of the sensor or cloudy weather.

3.2 Orbit determination

Measurements data provided by the image processing give a line of sight without range information. In order to obtain an orbit, the dynamic motion of the objects through the time should be used. This is the goal of the orbit determination algorithm. An accurate orbit determination can only be obtained considering an a priori knowledge of the orbit.

The a priori orbit and the list of measurements are used to compute the accurate orbit. Accuracy will depend on the quantity and the repartition of the measurements vs time.

The results of this orbit determination are given in 3 standardised formats stored in the database:

- NORAD Two Line Elements (TLE)
- CCSDS Orbit Ephemeris Message (OEM)
- CCSDS Orbit Parameter Message (OPM)

3.3 Data management and access

Angular measurements and orbits are accessible through the datacenter interface, given the SSC number of the object of interest.

Besides, the datacenter provides the ability to represent the neighborhood of an object of interest, through a graph called “Space Traffic Monitoring”. An example is given below.

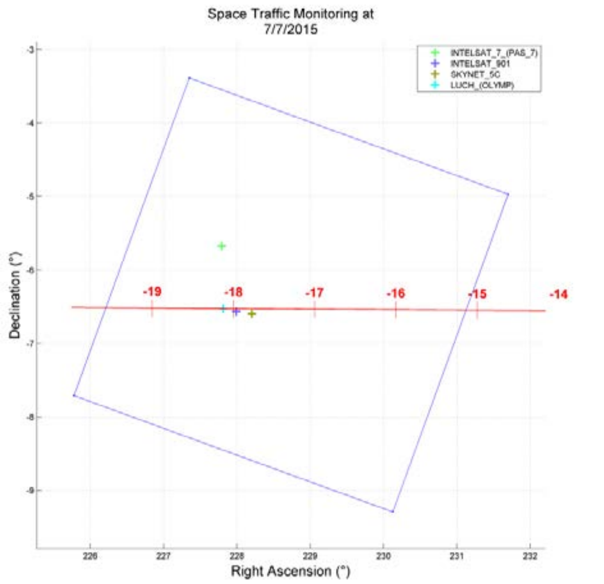

Figure 8. Example of Space Traffic Monitoring graph, showing the proximity of Luch Olymp to Intelsat 901 in July 2015

A visualizer provides the ability to visualize the position of objects on a 2D or 3D maps. The visualizer can display the orbit at a specified date of one or several specific objects or all the objects stored in the database and the position of the stations (blue point on the Earth). An example is given hereafter.

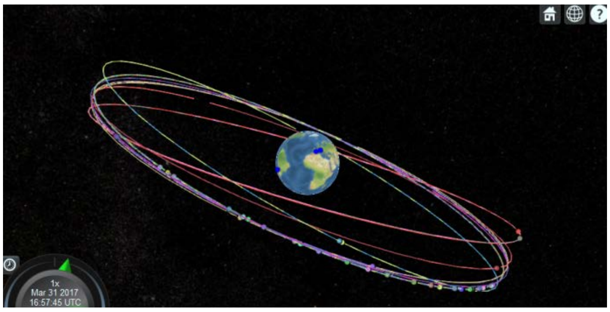

Figure 9. 3D view of the visualizer with several GEO catalogued objects

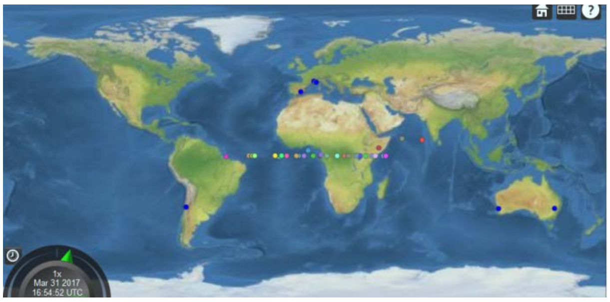

Figure 10. 2D view of the visualizer with several GEO objects catalogued from European stations

4 SYSTEM PERFORMANCES

4.1 Sensitivity

The detection sensitivity depends on the optics diameter and on the exposition time.

We express the brightness of spatial objects as magnitudes, which is the same scale that is used to measures star brightness. Magnitude is an inverted logarithmic scale, which means that the lower the magnitude is, the brighter the object is. The apparent magnitude of a spatial object depends on a lot of parameters such as size and material, distance, phase angle and atmospheric transmission.

Our tracking stations are able to detect metric size objects on GEO orbits, which corresponds roughly to magnitude 16 (depending on observation conditions and target characteristics).

For example, we tracked successfully the following objects:

- SYLDA, residual part of Ariane 5 double launches, orbiting in GTO. Being all painted black, it can appear very faint depending on the lighting conditions (up to magnitude 15).
- INTELSAT 3-F7, very small communication satellite, launched in 1970. Its metric size makes it appear very faint (up to magnitude 16).

4.2 Angular accuracy

The angular accuracy of the coordinates produced is expected to be theoretically better than 1 mdeg. We had the opportunity to challenge this accuracy by comparing the measurements to well-known orbits of operational Eumetsat satellites. The RMS residuals obtained were lower than 0.35mdeg, which is even lower than expected.

Angular accuracy in LEO is under characterisation.

4.3 Orbit determination accuracy

The angular measurements produced by the stations are used for orbit determination purposes in GEO.

The following 2 figures show the accuracy of the orbit determination for a propagation period of 1 month. The orbit generated with our system has been propagated during 1 month and for each real measurement obtained, the expected measurement has been computed in order to be compared with the real one. The Figure 13 and Figure 12 display the difference (residual) between real and expectation for 2 stations of the network. We can see a very good accuracy on the declination axis (noise below 0.5 mdeg) on the entire duration of the propagation. The noise for right ascension is a little bit higher with a value around 1 mdeg. Those results show the accuracy of the orbit determination process and the measurement generation. The corresponding orbital position accuracy is below 500m immediately after the orbit determination.

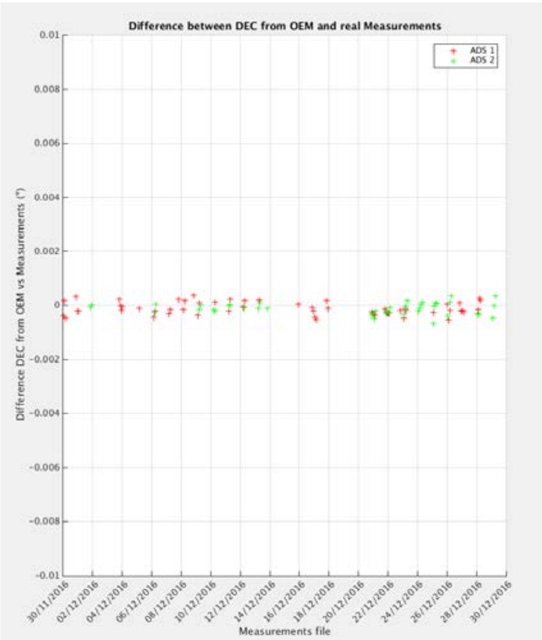

Figure 11. Residuals between real measurements and 1-month propagated orbit on declination axis

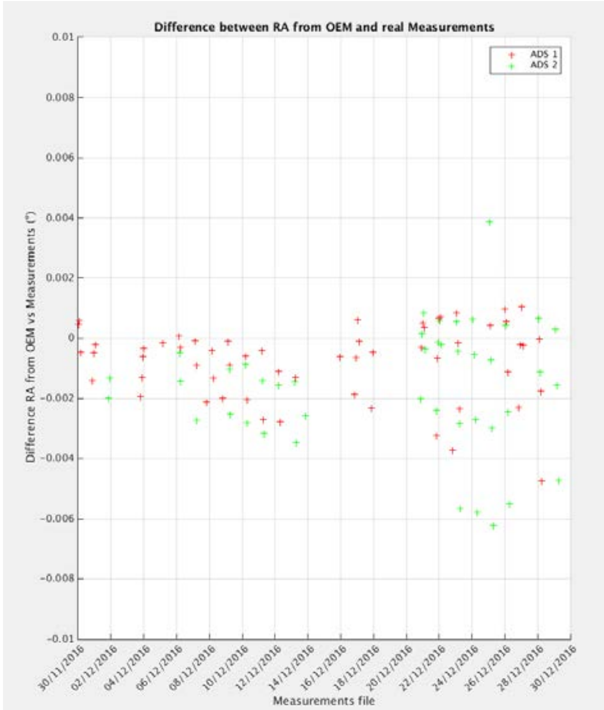

Figure 12. Residuals between real measurements and 1-month propagated orbit right ascension axis

The obtained accuracy allows various applications that are not possible or grandly limited with public Two-Line Elements (TLE).

5 APPLICATIONS

The stations associated with the datacenter allow to easily maintain a catalogue of accurate orbits for objects of interest, thus to become autonomous with respect to the SpaceTrack TLE catalogue.

Thanks to its ability to provide accurate angular measurements and maintain orbit catalogue, Airbus Safran Launchers can provide services to its customer.

One application is supporting the conjunction analysis for operational satellites. End of 2016, Eumetsat signed a contract with Airbus Safran Launchers for conjunction support on its fleet. Following the reception of Conjunction Data Message (CDM), Eumetsat sends Airbus Safran Launchers a request for the provision of accurate orbit for Eumetsat satellite and secondary object (debris). Thanks to its catalogue, Airbus Safran Launchers is able to provide the data within 2 hours, and also provides updated orbits of both objects the following days, until the conjunction date. Thanks to these data, flight dynamics team can refine conjunction analysis to plan appropriate actions.

The data below give an example for a conjunction between METEOSAT 11 and GORIZONT 27:

JSpOC TCA : 2016-12-24T19:21:15.754

(Time of Closest Approach)

MISS_DISTANCE = 17448 [m]

Airbus Safran Launchers miss-distance: 17.456km

The comparison of JSpOC CDM data with conjunction data obtained from Airbus Safran Launchers catalogue and conjunction analysis algorithm showed that the results are very close.

Airbus Safran Launchers also uses a conjunction prediction algorithm which allows the anticipation of CDM. It has also been validated with respect to JSpOC data.

The accuracy proved in the previous section allowed us to determine a threshold under which the difference between expected and real measurements should be if the object follows a ballistic propagation. If the difference exceeds this threshold, this shows that non-natural propagation occurred: we can detect maneuvers. This can be useful for object characterization (active vs debris), or for the validation of operational satellites manoeuvers.

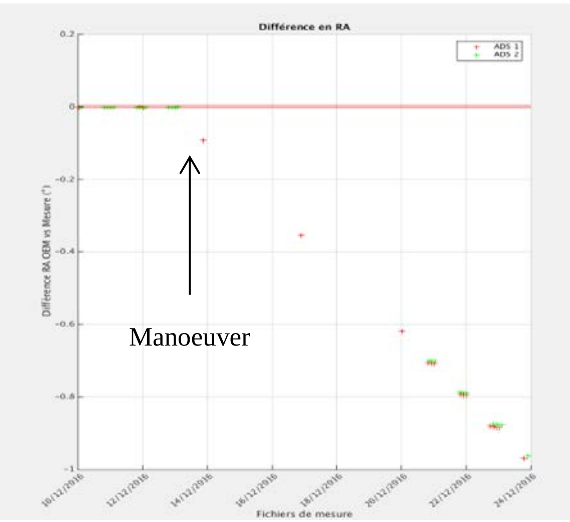

Figure 13. Example of manoeuver detection using residuals between real and expected measurements

Besides, the provision of accurate angular measurements can be used for the calibration of Telemetry/Telecommand (TMTC) antennas, mean usually used to localize operational satellites.

Airbus Safran Launchers can also provide zone surveillance service. Indeed, regular observations of satellites of interest can allow the detection of potentially threatening objects in the immediate neighborhood. An example was showed in Figure 8 with the case of Russian satellite LUCH-OLYMP which came close to Intelsat 901 for unknown reasons.

6 CONCLUSION AND PERSPECTIVES

Airbus Safran Launchers optical network has been deployed between 2014 and 2017 and is now fully operational. Thanks to its associated datacenter, the exploitation of the data allows the provision of services to various entities, from civilian satellite operator to military organisation.

Moreover, Airbus Safran Launchers is perpetually working on the development of its space surveillance abilities.

We are currently working on an automated system that could allow resolved imaging of LEO satellites. A first demonstration as proof-of-concept was achieved in 2016. The automation and enhancement of the image acquisition and image processing algorithm are in progress.

The orbit determination included in the datacenter currently only manages GEO orbit determination. We plan to make the algorithm compliant with all altitude orbits, in order to improve the processing of data acquired on LEO objects.

Besides, in order to ease object identification, we are still working on photometry measurements, and plan to add filters. The spectral measurements shall give some interesting information about object material and help with the identification.

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