Sstod

ORBIT DETERMINATION AND SENSOR CALIBRATION SOFTWARE

GMV's ***Sstod*** COTS software is a software application for orbit determination, sensor calibration and correlation based on Space Surveillance and Tracking (SST) sensors data able also to perform auxiliary computations like orbit propagation, interpolation and comparison, and TLE propagation, estimation and fitting, reference frame conversion, orbit format conversion, plot generation, etc. It is based on the well-known and operationally proven ESA's NAPEOS technology, used in tens of missions and a wide variety of scenarios including Flight Dynamics (FD), Precise Orbit Determination (POD), Navigation (GNSS) and SST.

These systems have been proved under **stringent operational conditions** and for a wide set of customers including 30+ satellite operators with hundreds of satellites in all orbital regimes (LEO, MEO, HEO/GTO, GEO) and space agencies like NASA, ESA, EUMETSAT and DLR, among others.

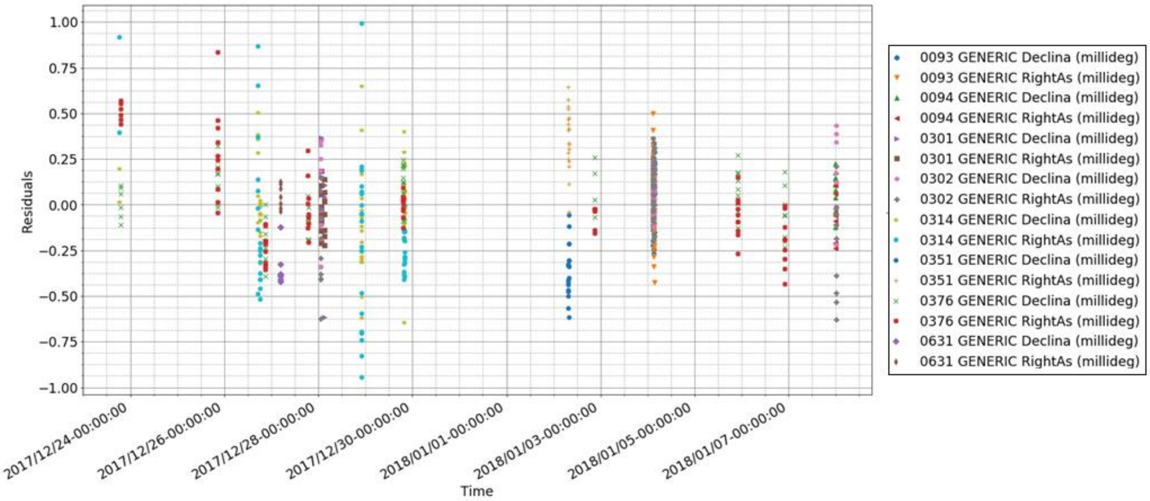

Figure 1: Orbit determination residuals with *Sstod* (single object, network of telescopes)

Among many other uses, ***Sstod*** has been used for orbit determination purposes with telescopes, radar and SLR data and SST sensor calibration of the Spanish SST Operations Centre (**S3TOC**, since 2017), of the Operations Centre of the Polish SST System (**SSAC-PL**, since 2019), of the Operations Centre of the Romanian SST System (**COSST**, since 2020), of the Spanish military Centre of Operations of Space Surveillance (**COVE**, since 2022), and also of the military German Space Situational Awareness Centre (**GSSAC**, since 2023).

Additionally, ***Sstod*** is currently being used as SST data processing infrastructure and orbit determination and sensor calibration system for a large number of campaigns for ESA, EUMETSAT and other space agencies as well as for a large number of commercial satellite operators.

Finally, ***Sstod*** has been operationally used since 2014 for orbit determination purposes with data from a wide variety of telescopes, radar, laser stations and passive ranging stations. Among others, it has been used for the processing of SST sensors data from the following SST sensors:

- **Telescopes**: Exoanalytics network, Numerica/Slingshot network, TJO, TFRM, IAC, Bootes, DeSS, TAROT, Starbrook, OGS, GeoTracker, 6ROADS, OA-AMU, Panoptes, Solaris, AROA.
- **Radars**: TIRA, Chilbolton, MSSR and S3TSR, BSSR and GRAVES, LeoLabs radars.
- **SLR sensors**: ILRS network including the observatory in Graz (Austria) for debris.
- **Passive ranging**: SDS passive ranging network

In **orbit determination mode**, the software includes a **batch least-squares** process to obtain the orbit that minimizes the residuals of the measurements. In **orbit propagation mode**, a previous state vector is propagated along time.

In both cases, the **orbital dynamics models** included in the process are fully configurable including geopotential of the Earth, solar radiation pressure, third-body forces from planets, the Moon and the Sun and various other force models. The achievable accuracy with the dynamical models mentioned above is well below the centimeter

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level. As a result, the main limitation on the achievable accuracy in orbit determination is the measurements accuracy.

The **measurement types** supported are one way and two-way range, one way and two-way range-rate (Doppler), space-based and ground-based inertial angles (right ascension and declination) and topo-centric angles (azimuth and elevation) as well as Time Difference of Arrival (TDoA). As a result, it supports the processing of sensors data from telescopes, radar, SLR stations and passive ranging stations for SST purposes and also from ranging stations, GPS, SLR and DORIS sensors, among others. It implements state-of-the-art **measurement correction models** including troposphere, ionosphere and annual aberration, etc.

From an **interface** point of view, most of the execution-dependent information is passed to the software through clearly defined **file-based interfaces**. Moreover, the software has been designed to comply with standard interfaces (CCSDS TDM, CDM, OPM, OEM and OMM) for sensors data and orbital data. Additionally, it supports the ephemerides formats provided by CSpOC (TLEs and SP catalogue).

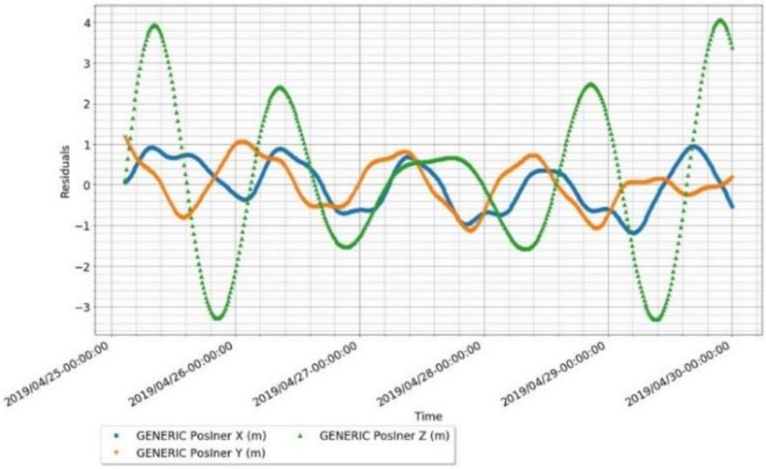

Figure 2: Orbit fitting to SP catalogue residuals with ***Sstod***

In terms of **performances**, ***Sstod*** has also proven to be extremely efficient not only in terms of **accuracy** (POD-capable with centimeter accuracy), but also in terms of **runtime performances** (e.g. used for GNSS-based applications with satellite constellations processing millions of measurements), exploiting the capabilities of intensive **parallelization** within a multi-core processor or a cluster of processors, although it can also be executed in simple HW (e.g., a laptop). It has been used in scenarios dealing with very long arcs, weeks and even months, (GEO telescopes scenarios), involving the use of large amounts of data (e.g. LEO radar scenarios) and solving for a large number of parameters (even snapshot clock solutions and integer ambiguities for GNSS). The regular SST-like scenario involving the processing of optical and radar data mainly (and fusing it with other phenomenologies) and estimating a relatively reduced set of parameters along a short- to medium-length arc involves extremely reduced processing times.

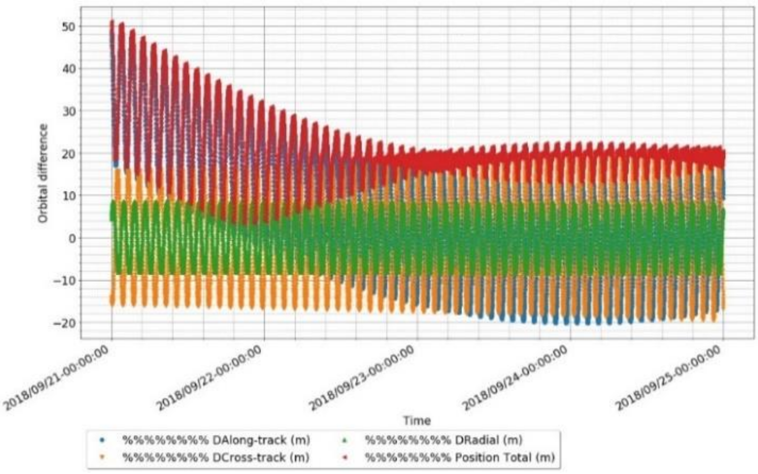

Figure 3: Orbit comparison with ***Sstod***