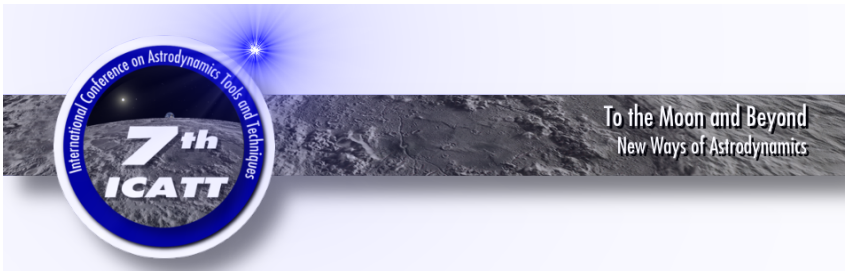

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Correlation techniques to build-up and maintain space objects catalogues

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Human activity in the space has caused the growth of a very large population of resident space objects (RSO). More than 19,000 objects are currently catalogued by 18th SPCS (former JFSCC) with sizes starting around 10 centimetres in LEO and around 1 metre in GEO. Space debris has nowadays become a very important thread to space operations as high-risk collisions are predicted daily between operational spacecraft and space debris objects.

Most space agencies have their own programs to deal with this thread, both from a mitigation point of view (IADC guidelines implementation, spacecraft design, active space debris removal), and from an operations point of view (e.g., space surveillance and tracking, collision avoidance). On the other side, the space private sector has been developing and using its own solutions to tackle the problem.

One of the key aspects to implement such measures is the availability of a catalogue of RSOs, not only characterising the properties of the objects, but also providing precise ephemerides that allow the prediction of high-risk collision events accurate enough and time in advance.

To build-up and maintain a RSO catalogue, in addition to the required sensors (radars, telescopes, SLR stations), it becomes necessary to have the required ground-segment infrastructure able to process efficiently all the data provided, in form of observation tracks, from those sensors.

Since 2007 GMV has developed and used methods to identify, track and catalogue RSOs. The SST Catalogue Maintainer Software (***catmai***) is GMV's software capable of maintaining a catalogue of man-made Earth orbiting objects and their orbital information through the processing of measurements from a pre-defined space surveillance network of sensors.

catmai is composed of an initial orbit determination tool, an orbit determination module, a track-to-orbit correlator, a track-to-track correlator, an orbit-to-orbit correlator and a catalogue post-processing component for the analysis of the cataloguing performances.

This paper will focus on the methods implemented in GMV's cataloguing solution and their performances in terms of success rate and false positive detection for the following processes:

- **Initial orbit determination**, to obtain the first estimation of the orbits from very few observations and with no a-priori information. A set of initial orbit determination methods are available for different number and type of measurements.
- **Orbit determination**, to improve the first estimation of the orbits by considering all available data, via both sequential and batch least-squares approaches. These methods are used during the correlation processes as well as for updating catalogued orbits.
- **Track-to-orbit correlation**, to correlate uncorrelated tracks (UCTs) with already catalogued objects for catalogue maintenance. Correlation is performed in the measurements domain, i.e. synthetic measurements are compared against real ones provided by the sensor network. The figure of merit considered is the distance between real and synthetic tracks (Euclidean, Mahalanobis or Bhattacharyya). The track-to-orbit correlation algorithm involves: *Synthetic tracking generation*, *pre-filtering*, *Synchronisation*, *Residuals computation* and *Correlation statistics computation*.

The performance of the track-to-orbit correlator has been evaluated on both optical and radar cataloguing maintenance scenarios. It is able to provide success rate around 99.5% (true positives), around 0.6% of false negatives while avoiding false positives.

- **Track-to-track correlation**, to associate and correlate UCTs among them in order to identify new objects not previously catalogued (i.e. catalogue build-up).
  The main concept behind this track-to-track association method is a multi-step filter that sequentially applies IOD and simple OD methods to all possible combinations of uncorrelated tracks from survey activities.
  The performance of the track-to-track correlator has been analysed on radar cataloguing build-up scenarios, leading to success rates around 99% (true positives) and the false positive rates lower than 0.1%, while keeping a high track usage rate (close to 99%).
- **Orbit-to-orbit correlation**, to correlate objects of the catalogue with those from external catalogues such as Space-Track's public catalogue. The correlation information of all objects of the involved catalogues is maintained from one analysis to another. This history of the correlation process is stored and used to ensure that two objects that used to correlate keep on correlating even if there is a manoeuvre not detected in one of the orbits through an outlier detection process.

The performance of the orbit-to-orbit correlator has been investigated by correlating a precise catalogue with the Two-Line Element Sets (TLE) catalogue for more than 15,000 objects. Results after one month of analysis reveal a success rate of more than 99.9% (true positives), around 0.08% of false negatives and only less than 0.01% of false positives.

The experience on these subjects gained by GMV with its own software solution for catalogue build-up and maintenance will also be described in the paper, using data from real sensors: more than 30 telescopes, radars and SLRs in five continents, covering all SST telescopes in Spain (OAM, TFRM, TJO, IAC, IAA), Airbus's GEOtracker telescopes, SpaceInsight telescopes, AIUB telescopes in Switzerland, ESA's OGS, Russian ISON telescopes network, and radars such as TIRA in Germany, Chilbolton in UK, ESA's MSSR, and the Spanish Navy SLR station, among others.

Summary

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