Orbit determination by merging optical, radar and laser measurements

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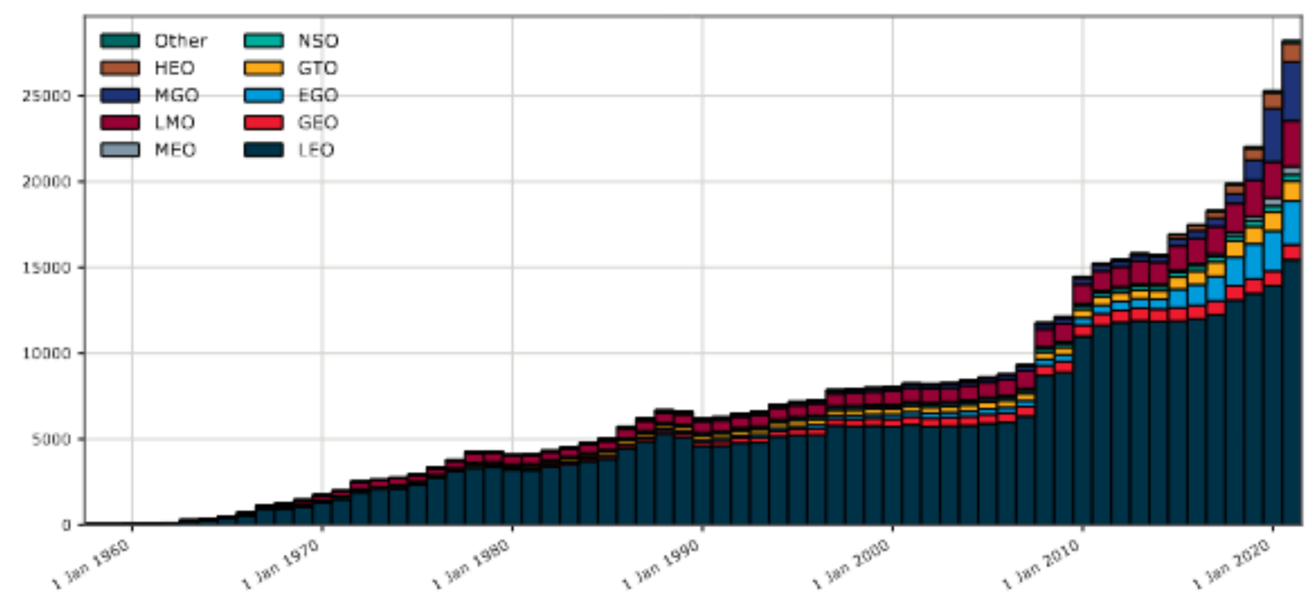
Abstract

The proliferation of space debris puts the continuity of space missions at risk and poses a serious challenge to be faced. The number of objects classified as space debris is increasing rapidly, especially in regions of high interest for commercial or scientific exploitation (LEO and GEO). Due to the high added value of these regions, the cataloguing, and more specifically, the orbit determination of space debris objects has become a topic of great importance and growing interest.

This study outlines the Initial Research Plan of the doctorate entitled “Orbit determination of space debris objects from the fusion of the information obtained by different sensors”, included in the Aerospace Engineering Doctorate Program of the Carlos III University of Madrid. The main objective of this study is to analyse the benefits of merging laser distances, radar observations and angular measurements in the same orbit determination process.

During the development of the thesis, access to data from different sensors will be available for scientific exploitation: a) laser measurements from stations belonging to ILRS, b) angular measurements from the TFRM telescope and c) observations from the S3TSR radar. With the use of these real measurements, it is intended to show how the observed objected-sensor geometry affects the results, as well as the precision of the sensors used, the number of observations and the observed arc length, among other factors. Likewise, it is intended to investigate the different algorithms and mathematical methods that lead to orbital determination and to explore techniques that allow real-time corrections to be applied to the analysed orbits.

Intro



Evolution of the number of objects depending on the type of orbit.
ESA Annual Space Environment Report 2022

The unstoppable development of space technology has led to a drastic growth in the number of missions. At the same time, these have generated a serious side effect problem, the proliferation of space debris. Space debris has a negative impact on missions with active satellites, and it will certainly do so on future ones. For this reason, perfecting detection, tracking and cataloging techniques, as precisely as possible, is the first step in the right direction to get control of this issue.

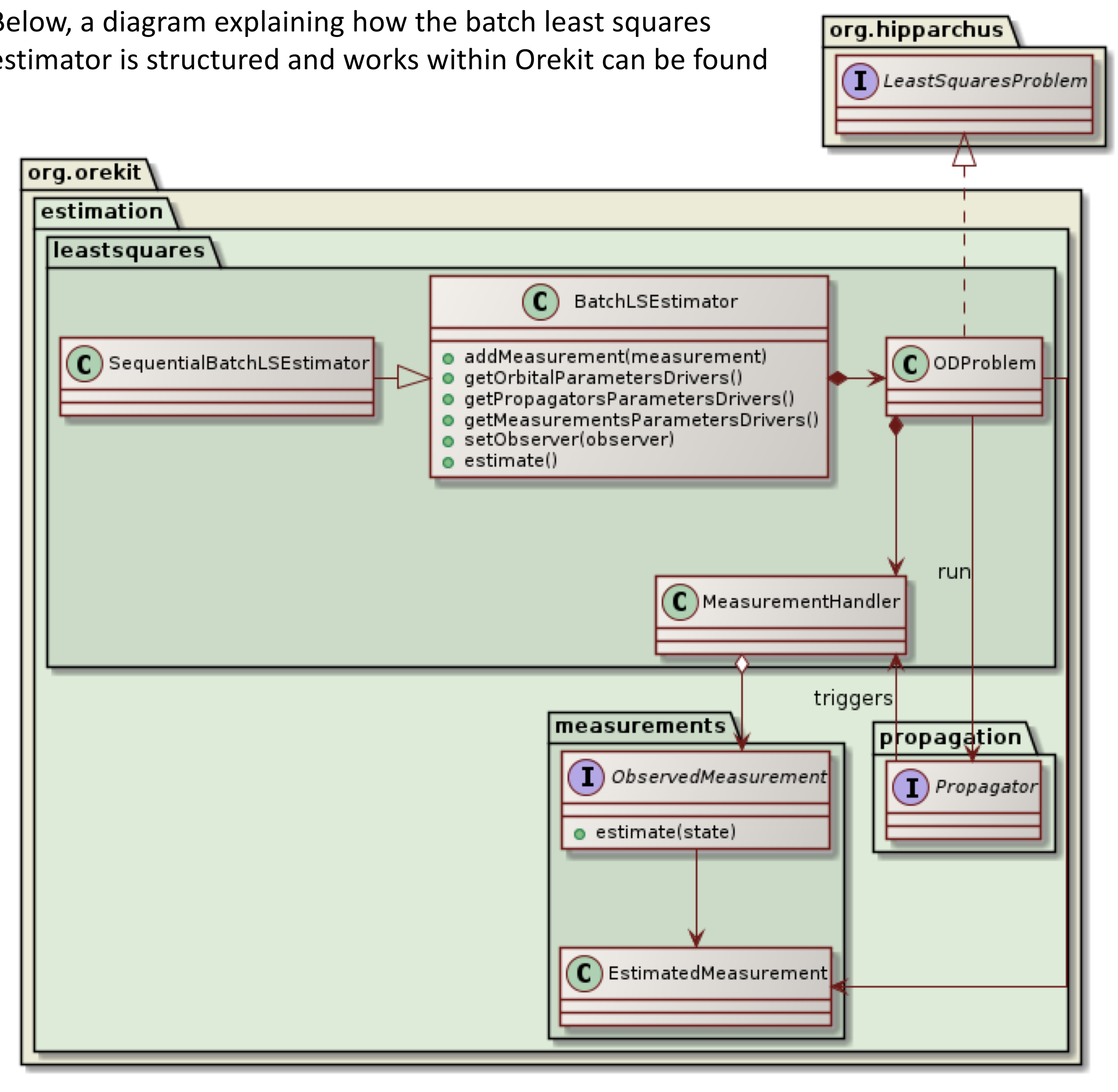
Orbit determination - Estimators

Orbit determination can be described as the process that allows defining, at different instants of time, the state vector of an object in orbit. The motion of the object is approximated by a set of equations, from which the state is updated using a set of discrete observations and subject to random and systematic errors. The orbiting object is assumed to be influenced by various external forces, including atmospheric drag, solar radiation pressure, perturbations generated by third-party bodies, tidal effects of the Earth, and finally, general relativity.

Currently, there are three groups of algorithms that are used in solving the orbit determination problem: **batch estimators**, whose main method is least squares, recursive or **sequential estimators**, characterized by Kalman filters and, finally, mixed estimators that using Bayesian filters combine the advantages of the previous two.

Orekit, an open orbital dynamics library, has been used to carry out the orbit determination process. This library provides the framework with higher-level interfaces and classic implementations, such as the use of angular measurements and distances. The design features of this library provide enough tools for classical orbit determination and can be extended to address more operational needs.

Below, a diagram explaining how the batch least squares estimator is structured and works within Orekit can be found



Orekit's LSQ estimation process operating scheme.
Orekit Documentation

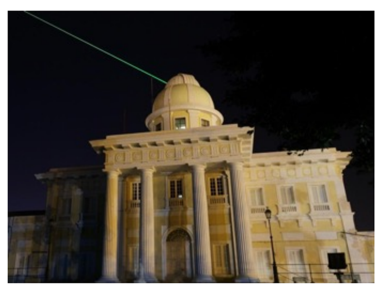
Objectives

- Implement OD through the combined use of RADAR, optical and LASER observations for the generation of improved orbits.
- To study the impact that the fusion of the information obtained by the three sensors has on the OD. Check the efficiency of the algorithms developed, improve them and solve possible errors.
- Analyse how the variation of the different factors affects the precision reached in the OD process: sensor-object geometry, observed arc length and number and distribution of observations

Observation Campaigns

LASER ROA

San Fernando. Royal Observatory of Spanish Navy
Tracking
LEO - MEO: 500 - 20.000 km
No azimuth restrictions (360º)
Night observations



TFRM

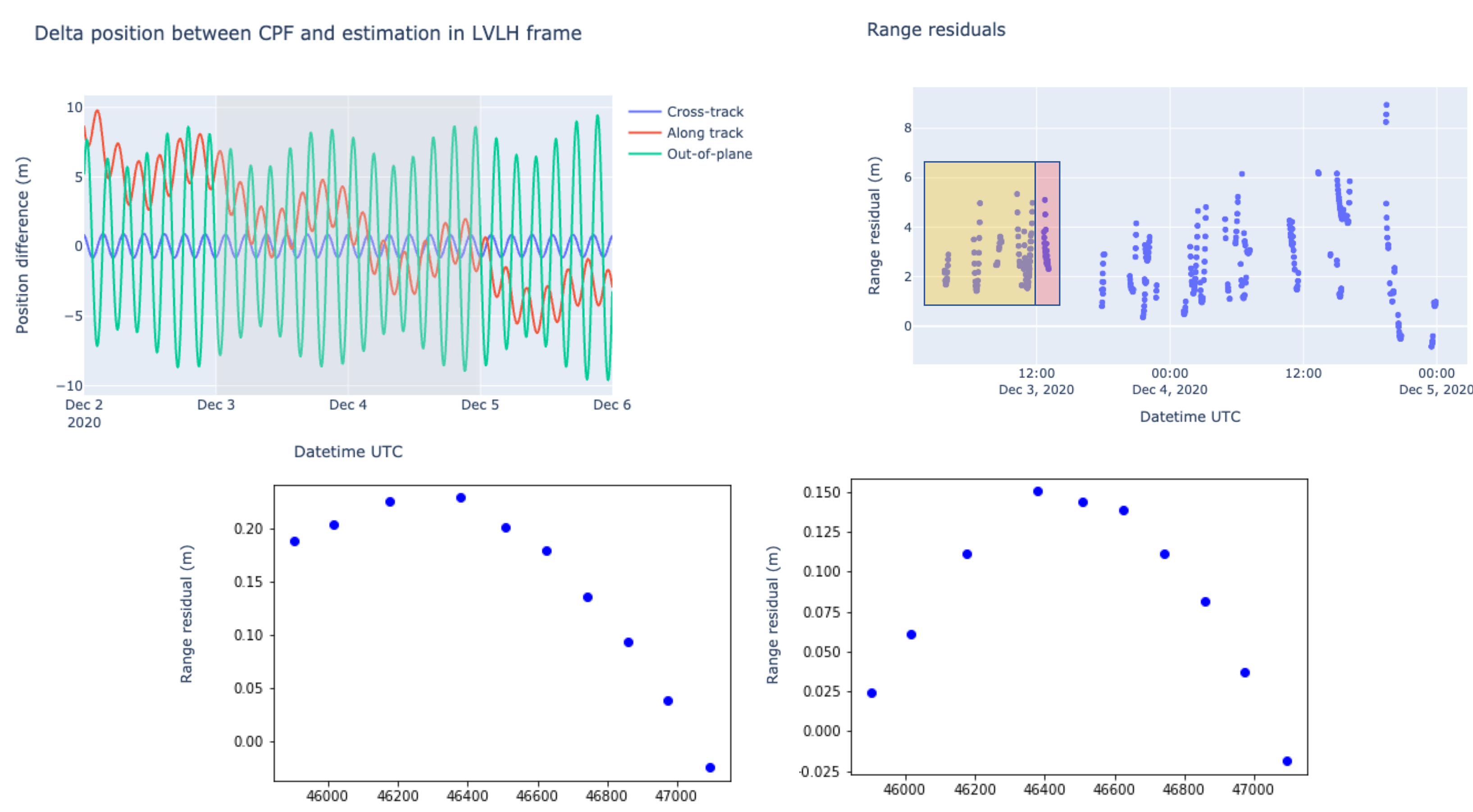
Montsec. Pre-Pirineo Catalán
Surveillance & Tracking
LEO - MEO - GEO
No azimuth restrictions (360º)
Night observations

RADAR S3TSR

BA Morón de la Frontera
Surveillance & Tracking
LEO: 200 - 2.000 km
FoR: 180º FoV (facing South)
Day and night observations

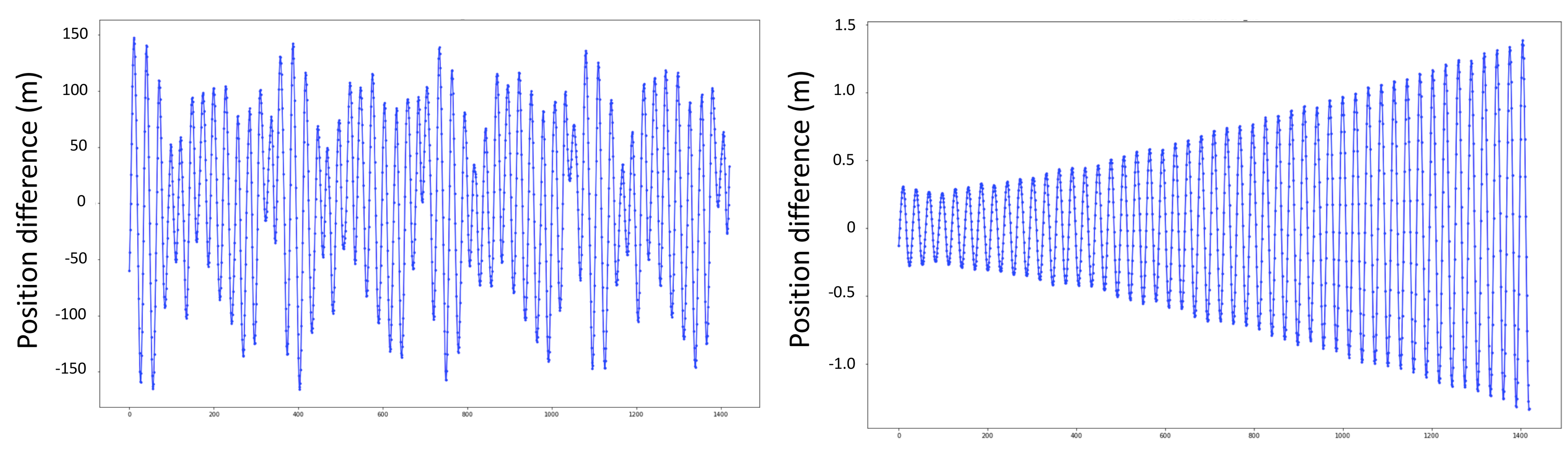
OD tool validation

To verify the correct functioning of the algorithms used, two comparisons have been made: the first one has consisted of using a reference tracking obtained by a laser station and checking how the residuals are reduced after carrying out the OD.



Analysis of residuals from a reference tracking carried out by Mt Stromlo station on the Lageos 2 satellite before (left) and after carrying out the OD (right).

The second check was to use the precise SP3 orbits of different satellites (Lageos 1-2, Ajisai, etc) and compare them with the results of the OD process.



Analysis of the differences between the precise SP3 ephemeris and the orbits generated after the OD for the Ajisai satellite during a period of 3 days. On the left side considering the initial TLE and on the right the improved orbit.