Aerospace Europe Conference 2023
Joint 10th EUCASS – 9th CEAS Conference

Abstract #XXX *(to be filled by the organizers)*
Preferred Topics: SUSTSP
Corresponding author: LOSACCO Matteo
e-mail of corresponding author: matteo.losacco2@isae-supaero.fr
Type: Oral
Status of corresponding author: Regular

From short to too-short arcs: admissible states region theory for ground-based observations

Matteo Losacco [1], Laura Pirovano [2], Roberto Armellin [3], Carlos Yanez [4], Emmanuel Delande [5], Stéphanie Lizy-Destrez [6]*

** Corresponding author*
[1] Postdoctoral researcher, ISAE-SUPAERO, 10 Avenue Edouard Belin, 31400, Toulouse, France, matteo.losacco2@isae-supaero.fr
[2] Postdoctoral researcher, Te Pūnaha Ātea- The Space Institute, 20 Symonds Street, 1010, Auckland, New Zealand, laura.pirovano@auckland.ac.nz
[3] Professor, Te Pūnaha Ātea- The Space Institute, 20 Symonds Street, 1010, Auckland, New Zealand, roberto.armellin@auckland.ac.nz
[4] Altimetry specialist for hydrology, CNES, 18 Av, Edouard Belin, 31400, Toulouse, France, carlos.yanez@cnes.fr
[5] Space Surveillance engineer, CNES, 18 Av, Edouard Belin, 31400, Toulouse, France, Emmanuel.delande@cnes.fr
[6] Associate professor, ISAE-SUPAERO, 10 Avenue Edouard Belin, 31400, Toulouse, France, stephanie.lizy-destrez@isae-supaero.fr

Abstract

Space Situational awareness tasks require an accurate estimation of the state of objects orbiting around the Earth. These estimates are mainly derived from networks of ground-based optical, radar, and laser sensors that operate worldwide to monitor the near-Earth environment continuously. This surveillance action currently covers just a small portion of the Resident Space Objects (RSO) population, whose size is constantly growing due to the unrelenting launch activity, coupled with in-orbit object generation events, such as collisions, fragmentations and explosions. As a result, observation campaigns often offer the possibility of identifying and potentially characterizing uncatalogued objects.

Once detected, the state estimation process of an uncatalogued object begins with the so-called Initial Orbit Determination (IOD), which is the process of extracting a guess state from a set of measurements. Such measurements are typically called tracks, tracklets, or short arcs and can be processed by well-established methods [1]. Conversely, the passage is referred to as a too-short arc whenever the available observations are too close in time and/or too uncertain to perform IOD. Different approaches were developed to extract meaningful information from too-short arcs, e.g. the Admissible Region (AR) [2].

One major drawback of literature methods for IOD and AR is the lack of information on the estimated uncertainty of the solutions. Estimating the solution uncertainty is however essential to establish robust data association schemes enabling catalogue initialization. Differential algebra (DA) has been recently proposed to map the observations' uncertainty into state uncertainty. DA-based reformulations of the IOD problem, called DAIOD methods, were presented in [3-5] for range radars, optical sensors and Doppler radars. A six-dimensional extension of the AR concept, called admissible states region (ASR), has been recently formulated by [6].

Leveraging DA techniques, we aim to tackle another existing limitation of the available state estimation theory: the absence of a clear boundary between the short and the too-short arcs regimes. The first part of this work develops a metric for identifying such boundary. The proposed approach applies an automatic domain splitting algorithm [7] to the Taylor expansion of the determinant of the Jacobian of the IOD transformation, mapping deviations in the available

measurements to deviations in the estimate. Polynomial bounding techniques are then applied to each generated subset to identify whether singularities are included in any of them. If no singularity is detected, the IOD problem is well posed; thus, DAIOD methods can be applied. Otherwise, the ASR theory shall be employed. Once the boundary between the DAIOD and the ASR regimes is identified, the second part of the work illustrates the basic concepts of the ASR theory and extends it to all ground-based sensor types. Pruning techniques based on Keplerian elements and measurement residuals are then applied to reduce the initial ASR size progressively.

Once the theory is laid out, examples of boundary cases are presented. Depending on the tracklet length and observation precision, the metric determines the best approach to extract a state from the data available, and examples of ASRs for different sensors are shown.

References

[1] J. C. Dolado-Perez, C. Yanez, and A. Anton, "On the performance analysis of Initial Orbit Determination algorithms", Proc. 67th IAC, 2016.

[2] D. Farnocchia, G. Tommei, A. Milani, and A. Rossi, "Innovative methods of correlation and orbit determination for space debris", Celestial Mechanics and Dynamical Astronomy, Vol. 107, 2010, pp. 169–185, https://doi.org/10.1007/s10569-010-9274-6.

[3] R. Armellin and P. Di Lizia, "Probabilistic Optical and Radar Initial Orbit Determination", Journal of Guidance, Control, and Dynamics, Vol. 41, No. 1, 2018, pp. 101–118, https://doi.org/10.2514/1.G002217.

[4] L. Pirovano, D. A. Santeramo, R. Armellin, P. Di Lizia, and A. Wittig, "Probabilistic data association: the orbit set", Celestial Mechanics and Dynamical Astronomy, Vol. 132, No. 15, 2020, https://doi.org/10.1007/s10569-020-9951-z.

[5] M. Losacco, R. Armellin, C. Yanez, S. Lizy-Destrez, L. Pirovano, and F. Sanfedino, "Robust initial orbit determination for short-arc Doppler radar observations", 2022, https://doi.org/10.48550/ARXIV.2204.13966.

[6] L. Pirovano, R. Armellin, J. Siminski, and T. Flohrer, "Differential algebra enabled multi-target tracking for too short arcs", Acta astronautica, Vol. 182, 2021, pp. 310–324, https://doi.org/10.1016/j.actaastro.2021.02.023.

[7] A. Wittig, P. Di Lizia, R. Armellin, K. Makino, F. Bernelli-Zazzera, M. Berz, “Propagation of large uncertainty sets in orbital dynamics by automatic domain splitting”, Celestial Mechanics and Dynamical Astronomy, Vol. 122, 2015, pp.239-261, https://doi.org/10.1007/s10569-015-9618-3