Report Research Activity

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This report summarises the activities carried out by the research fellow during the six months of activity, from November 25th 2021 to May 24th 2022.

The research activity is supervised by Prof. Giovanni F. Gronchi and Phd Giulio Baù and it is related to techniques for Initial Orbit Determination (IOD) of space objects from observations. In particular it is focused computation of several asteroid orbits with the observations of the Isolated Tracklet File (ITF) available at the Minor Planet Center and the application of the IOD to asteroids and space debris.

This activity belongs to the European project Stardust-R and it is funded by an MSCA-ITN-ETN - European Training Networks (see http://www.stardust-network.eu/ for more information).

Developments and work in progress:

We have mainly followed the work presented in the research papers of Orbit Determination with the two-body integrals I, II, III (see [2, 3, 4]) and the book by A. Milani and G. F. Gronchi [6]. In particular, our work was focused on the use of the polynomial method (see [4]) with the aim of identifying whether if two tracklets belong to the same observation and to construct a preliminary orbit (link2 problem). Similarly, we also have focused on the use of the method introduced in [5] with the aim of identifying whether if three tracklets belong to the same observation and to construct a preliminary orbit (link3 problem).

To this purpose we have made use of the software Orbfit (http://adams.dm.unipi.it/orbfit/), introducing some improvements in the implementation of the previously mentioned methods. In addition, thanks to the datasets provided by Robert Jedicke, these methods have been tested and analysed in various controlled conditions. We have made some improvements in the implementation of these methods and we are trying to use different techniques in order to recover lost solutions. For these datasets, we have found quite good results in terms of the total number of real identifications obtained.

In particular, we investigate the behaviour of these two methods for the computation of preliminary orbits. Our analysis is performed using both, synthetic and real data of main belt asteroids. The differences between computed and true orbital elements have been analysed for the true linkages, as well as the occurrence of alternative solutions. Some metrics have been introduced to quantify the results, with the aim of discarding as many false linkages as possible, keeping the vast majority of true ones. These

numerical experiments provide thresholds for the metrics which take advantage of the knowledge of the *ground truth*: the values of these thresholds can be used in normal operation mode, when we do not know the correct values of the orbital elements and whether the linkages are true or false. The results of these work can be found in an accepted paper in Icarus (see [7]).

An exploration of the ITF was done using a strategy combining the link2 and link3 methods mentioned previously. We are developing a graph based strategy to analyse the results obtained and to join linkages that belong to the same objects.

Secondment:

Host institution: Centre National d'Études Spatiales
Host supervisor: Carlos Yanez
Period: January 10, 2022 to March 31, 2022

During the secondment at Centre National d'Études Spatiales (CNES) the main goal was to study the numerical behaviour of the linkage method presented in [4] for the Initial Orbit Determination of the space debris using real data. We first analysed the numerical behaviour of the method with synthetic populations of observations, generated with different dynamical models and affected with different levels of astrometrical error. This allowed us to control the sensitivity of the method to the errors and to know which perturbative effects are necessary to consider. Finally, we applied this method to real data obtained by the TAROT network [1].

Items covered:

- Simulation of observational data using the Orbfit package and verification of results using PATRIUS software.
- Application of the linkage method to the different synthetic populations.
- Numerical analysis of the linkage method.
- Application of the linkage method to the TAROT data.

Activities:

I presented a talk in the following seminar:

- Barcelona UB-UPC Dynamical Systems Group Seminar, December 1.

Organisation activities:

I'm currently involved in the organisation of:

- Workshop "Theory, models and simulations in Celestial Mechanics", Pisa, June 14-16 (https://arnold.dm.unipi.it/wp/tmscm/).
- Mini-symposium at CEDYA (https://cedya2022.es/).

References

[1] Boër M., et. al. TAROT: A network for Space Surveillance and Tracking operations. In: 7th European Conference on Space Debris (2017).

[2] Gronchi, G.F., Dimare, L., Milani, A.: *Orbit determination with the two-body integrals.* Cel. Mech. Dyn. Astron. 107(3), 299–318 (2010)

[3] Gronchi, G.F., Farnocchia, D., Dimare, L.: *Orbit determination with the two-body integrals. II.* Cel. Mech. Dyn. Astron. 110(3), 257–270 (2011)

[4] Gronchi, G.F., Baù G., Marò S.: *Orbit determination with the two-body integrals. III.* Cel. Mech. Dyn. Astron. 123, 105–122 (2015)

[5] Gronchi, G.F., Baù G., Milani A.: *Keplerian integrals, elimination theory and identification of very short arcs in a large database of optical observations.* Cel. Mech. Dyn. Astron. 127, 211–232 (2017)

[6] Milani, A., Gronchi, G.F.: *The Theory of Orbit Determination.* Cambridge University Press, Cambridge (2010)

[7] Rodríguez, O., Gronchi, G.F., Baù, G., Jedicke, : *Numerical behaviour of the Keplerian Integrals methods for initial orbit determination.* Icarus, accepted. Available at `https://doi.org/10.1016/j.icarus.2022.115080` (2022)

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