November 2021

IAF ASTRODYNAMICS COMMITTEE

1. Introduction

The IAF Astrodynamics Committee was established more than four decades ago and is currently made up of about 30 members. The Astrodynamics Symposium, coordinated by the Committee and conducted at annually IAC, is an international forum for recent advancements in the areas of guidance, navigation & control, mission design, optimization and operations, orbital and attitude dynamics.

2. Summary

In the area of Guidance, Navigation & Control (GNC), theoretical as well as applied contributions have appeared in the domains of landing and in-orbit maintenance. As in various other scientific fields, there is a confirmed trend in the research to investigate the benefit of artificial intelligence (neural networks) for the definition of open-loop guidance (also on-board). In parallel, more realistic modelling of the equipment used in GNC (in particular, pulse thrusters) continue to be investigated in terms of impact versus a more simple approach. Two main recurrent themes are:

- autonomy: shift of the guidance & control planning and computations from the ground station to the on-board computer,
- GNC techniques: machine learning, reinforcement learning, potential function, sliding-mode control,

whereas the main applications are:

- reconnaissance and landing on small bodies: autonomous reconnaissance, trajectory optimization, landmark navigation,
- formation flight and swarms: decentralized control of swarms, reconfiguration control, optimal collision avoidance,
- orbital debris : uncertainty propagation, collision prediction, debris removal,
- Earth-Moon system: data-driven model predictive control, low-thrust station keeping and attitude control in Halo orbit.

In the context of mission design, operations and optimization, emphasis is on lunar missions, including satellites in NRHOs and deployment of microsatellite constellations. Missions to the Martian moons have gained interest, most likely in response to the role that Phobos and Deimos have been assigned in support to the Mars exploration program in the areas of telecommunications, radiation protection and infrastructure for transportation and operations. Trajectories to the asteroids and the outer solar system are also in the focus of recent research. From the methodology point of view, multi-objective trajectory optimization approaches have been developed which address system and operations uncertainty (even severe). The use of neural networks and tree-search like heuristics is more and more common.

The main topics and applications in the context of orbital dynamics can be summarized as follow:

- Multi-body dynamics: uncertainty prediction, data-driven analysis and identification of dynamical structures, optimal orbit transfers between invariant manifolds, Keplerian map theory for third-body effects, adiabatic invariant theory applied to capture dynamics,
- Earth orbit dynamics: efficient orbit propagation methods, deorbiting with the use of solar radiation pressure and J2 perturbation,
- Orbit dynamics in the Earth-Sun system: formation flying control using solar radiation pressure,
- Orbit dynamics in the Earth-Moon system: machine learning for orbit predictions, ballistic escape using lobe dynamics.

Studies in the area of attitude dynamics have developed along traditional as well as highly-challenging paths, such as with magnetic control and control moment gyros.

Novel techniques are being investigated, including visual serving based on tracking features identified in onboard captured images. Artificial intelligence techniques are a trend also for attitude control. The a-posteriori analysis of some attitude-related issues during the re-entry of Hayabusa-2 is remarkable and intriguing as all actual operation results can be.

3. The Breakwell Lecture – Prof. Martin Lara (Universidad de la Rioja, Logroño, Spain)

Prof. Martin Lara from Universidad de la Rioja, Logroño, Spain (in the photo with Prof. Daniel Scheeres and Prof. Anna Guerman) received the Breakwell Award from the International Astronautical Federation for his dedication and outstanding research on perturbation methods. Prof. Lara gave a keynote speech on the application of perturbation methods to Quasi Satellite Orbits and Libration Point Orbits.

4. Highlights

- Autonomy: shift of the orbital and attitude guidance & control planning and computations from the ground station to the on-board computer,
- GNC techniques: machine learning, reinforcement learning, potential function, sliding-mode control,
- Multi-body dynamics: decentralized control of swarms, reconfiguration control in formation flying
- Interplanetary missions: to the Moon, Mars with optimal orbit transfers between invariant manifolds and the four-body problem technique