The Astrodynamics Network

Reporting

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ASTRONET-II

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Final Report Summary - ASTRONET-II (The Astrodynamics Network)

AstroNet-II - The Astrodynamics Network
Final Report

AstroNet-II has been the European Research Training Network that has trained through research eighteen young scientist and engineers on a number of problems in astrodynamics, all of them of current interest to space agencies and industry. Fourteen partners composed the network, eight of them university departments and research institutes, and the remaining six aerospace companies and space agencies. During its execution (2012-2015) AstroNet-II has been coordinated by the Institut d'Estudis Espacials de Catalunya (IEEC) in Barcelona (www.ieec.cat) .

The network has organized four Training Schools, open to young researchers not enrolled in AstroNet-II, in which the following short courses were given by some of the best specialist in the field: An introduction to Differential Algebra, An introduction to MATLAB®/SIMULINK®, Astrodynamics of Asteroids, Attitude Dynamics and Control, Feedback and Automatic Control, Invariant Manifolds, KAM Theory and applications in Celestial Mechanics, Optimal Control and Applications, Orbit and Attitude Determination, Orbital Dynamics, Trajectory Optimization, Solar Sailing, Spacecraft Formation Flying, and Symbolic Manipulation in Astrodynamics. The lecture slides of all the courses are available at the network website: www.ieec.cat/astronet2/.

The main research topics that have been considered are: Trajectory Design and Control, Attitude Control and Structural Flexibility of Spacecraft, and Formation Flying. For these three topics, we have studied and developed methodological and theoretical questions, as well as their application to open problems in mission design and some related astronomical problems; to all of them the team members of the network have done contributions that are briefly listed in what follows.

The basic methodologies that have been developed and implemented are: a) a procedure for the non-linear propagation of uncertainties (in initial conditions and model parameters) in flows using Differential Algebra techniques, b) an automatic domain splitting procedure for the non-linear propagation of uncertainties in orbital dynamics, and c) a procedure for invariant manifold computations, using parameterization methods, together with the representation of the manifolds using Differential Algebra procedures. All these methodologies can also be applied to other problems, in different science fields, for which the numerical simulation of deterministic models with uncertainties is required.

The main theoretical questions studied are: a) the analytical investigation, using normal forms, of the dynamics around the collinear points, and its application to the determination of bifurcation thresholds of halo orbits, b) the study of disposal techniques for spacecraft in libration point orbits and its application to the Lisa Pathfinder spacecraft, c) the computation of analytic estimates and topological properties of the weak stability boundaries, d) the determination of heteroclinic and homoclinic connections between the triangular libration points in the Sun-Earth system, and the computation of quasi-satellite orbits for Solar observations, e) the modelling and optimisation of mid-course corrections along interplanetary transfers, f) the application of gravity assists using Earth and the Moon in the computation of spacecraft interplanetary trajectories, g) the Trojan problem, from a Hamiltonian perturbative perspective, using adapted normal forms and h) the application of the modelling of the Trojan dynamics to extra-solar planetary systems.

Some methods, mainly related to the study of formation flying problems, have also been developed. They are based in the results obtained by F. Cucker and S. Smale for the behavioral approach study of flocks, and are: a) the design of distributed attitude control laws for spacecraft in a formation, and b) the study of optimal formation configurations and the associated adaptive gains design. In addition to these two questions, and also related to formation flying problems from a more standard optimal control problem approach, we have also studied: c) the station keeping of spacecraft Coulomb formations using ASRE strategies to solve the associated nonlinear optimal control problem, d) the control of spacecraft formations using low thrust nonlinear time-delay feedback, and e) the orbit control of a formation, using low thrust propulsion, in the vicinity of Earth-Sun halo orbits around the L1 and L2 equilibrium points.

Because its current interest and relevance, special attention has been given to the study of the motion of a spacecraft in the vicinity of small bodies, such as debris, asteroids, NEOs or planetary moons. Some of spacecraft in the vicinity of small bodies, such as debris, asteroids, NEOs or planetary moons. Some of the questions that have been addressed are: a) the efficient modelling of small bodies gravitational potential for autonomous approach, b) an inverse dynamics approach to the guidance of spacecraft in close proximity of tumbling debris c) the design of libration point orbits in the proximity of highly-inhomogeneous satellites and its application to the Mars-Phobos system, d) the identification of new orbits to enable future mission opportunities for the human exploration of the Martian moon Phobos, and e) the study of vision-based guidance, navigation and control systems in missions to small bodies.

Some attention has also been given to questions related to the everyday more abundant micro and nano satellites. In particular the following problems have been studied and developed: a) strategies to stabilize nano-satellite platforms with a space camera and integrated mechanical parts, b) a FPGA hardware control design for modular nano-satellite attitude control system, c) the orbit and attitude stability of a solar sail on a displaced orbit, and d) the formation flying control of micro-satellites in the vicinity of the Earth-Moon libration point L4, using pulsed plasma thrusters.

The developed attitude studies done in the three problems above mentioned have allowed the study of the following attitude questions: a) the design of an optimal attitude motion planner for large slew maneuvers using shape-based methods, b) a motion planning method, using single polynomials, of attitude manoeuvres and c) the design of an attitude stabilization electromagnetic module for detumbling uncooperative targets, such as spacecraft or space debris. Closely related to these attitude studies has been: d) the development of a terminal entry phase trajectory generator for reusable launch vehicles

The results obtained have been presented at international conferences and meetings in the field, and also have been published in scientific journals. Preprints and offprints of most of them can be found in the network website, together with some short animations, done by the AstroNet-II members, explaining to a wide audience the work done.

Most of the ESRs of the network have done their PhD during their stay in the network or will finish it few months after the end of their contract, and high percentage of the recruited fellows, both ESR and ER, have found an employment in the space sector just very few months after their stay in AstroNet-II.

Two CELMEC VI prizes were awarded to AstroNet-II Early Stage Researchers: “CELMEC PRIZE: Celestial Mechanics for Planet Earth" to Marta Ceccaroni for her paper titled "Analytic perturbative theories in highly inhomogeneous gravitational fields; and "CELMEC Poster Prize" to Zubin Olikara for his poster titled "Disposal techniques for spacecraft in libration point orbits". Albert Caubet was the winner of the start-up ideas competition done during the Strathclyde’s Enterprise Academy, Glasgow, UK, 19-21 March 2013. It has been agreed that the robust trajectory planning method developed by Albert Caubet at Strathclyde will be tested in flight on the ESA’s OPS-SAT cubesat—to be launched in 2016.

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