05/4107 Electrostatic forces for satellite swarm navigation and reconfiguration.

Type of activity: Medium Study (4 months, 25 KEUR)

Background

After the flight experience of the satellite SCATHA (1979) it become apparent that the electrical charge of a satellite, induced by the interaction with the space plasma, could be controlled with good accuracy and with a low energetic requirement[1-2]. Due to the fast response that can be achieved by the charge actuators, high bandwidth control has been shown to be also feasible[2]. A number of studies[2-8] have recently addressed the dynamical modelling of what have been called Coulomb satellites, i.e. groups of satellites whose electric charge is controlled in order to achieve a certain relative dynamic exploiting the inter-satellite electrostatic forces. Some orbit control has also been envisaged[12] exploiting satellite charge control, but the number of Coulomb per kilogram needed is extremely high for interesting applications. The Plasma environment, crucial for the electrostatic forces to exert any inter-satellite action, is modelled as being stable and can be accounted for by using the Debye length. While it is clear that, being internal forces, Coulomb forces do not allow control of the center of mass of a certain group of satellites, some interesting results have already been obtained with regard to relative motion controllability. It is quite likely that if these forces will ever be used to activate “bindings” between orbiting satellites and to control their relative motion or positioning, these will be coupled with other kinds of propulsion systems able to control the absolute position of the satellites. It is on this interaction between the electrostatic inter-satellite forces and a more standard propulsion system that this study proposes to focus. This kind of hybrid actuation has not been studied before, but it could allow to efficiently navigate a swarm of satellites and to allow for their reconfiguration and formation keeping with a minimal amount of propellant. We will refer to a swarm of satellites actuated by this hybrid combination of electrostatic forces and conventional propulsion with the name “Satellitrons”. Different concepts may be envisaged such as that of combining an artificial potential based design of the swarm path planning[9-11] with the electrostatic forces as to obtain a collision avoidance strategy constantly activated. Another concept could be that of having a central positive charged satellite equipped with conventional propulsion and surrounded by negative charged ones who follow its movement. Quite interesting is also the consideration of the environment surrounding the Lagrange points where a Debye length of tens of meters could allow for an efficient exploitation of the electrostatic charges. In a visionary, but possible, scenario, micro or nano satellites could navigate together while electrostatic forces control their relative geometry keeping them in a bounded formation.

Study Objectives

This study should investigate on the possibility of combining inter-satellite electrostatic forces with standard propulsion systems in order to achieve a fully controllable system. The controller, when possible, should exploit the electrostatic forces, while the standard propulsion system could provide, at the cost of using some propellant, the complete controllability of the system.

The main objectives should be:

- To model and simulate the dynamic of Satellitrons in the Earth environment and on the Lagrangian points environment.

- To provide some estimates on the magnitude of the electrostatic forces that could be available in various scenarios and provide an estimate on the maximum magnitude of its rate of change.

- To assess the possible benefits of the exploitation of electrostatic forces in connection with artificial potential based path planning of satellites swarm.

Proposals and assessments on different space concepts related to the exploitation of inter-satellites electrostatic forces are also welcome and encouraged.

The study will be performed in close cooperation with the ACT, and its results should be at a high standard that makes them suitable for publication in a peer reviewed journal.

References

1. L.B.King, G.G.Parker, S.Deshmukh, J.H.Chong, "Propellantless Control of Spacecraft Swarms using Coulomb Forces" NIAC Final Report, 2002.
2. H. Schaub, G. G. Parker and L. B. King, "Challenges and Prospects of Coulomb Spacecraft Formations," AAS John L. Junkins Astrodynamics Symposium, College Station, TX, May 23–24, 2003, Paper No. AAS-03-278.
3. H. Schaub, "Stabilization of Satellite Motion Relative to a Coulomb Spacecraft Formation," AAS Spaceflight Mechanics Meeting, Maui, Hawaii, Feb. 8–12, 2004. Paper No. AAS 04-259.
4. H. Joe, H. Schaub, and G. G. Parker "Formation Dynamics of Coulomb Satellites," 6th International Conference on Dynamics and Control of Systems and Structures in Space, Cinque Terre, Liguria, Italy, July 18–22, 2004.
5. H. Schaub and M. Kim, "Orbit Element Difference Constraints for Coulomb Satellite Formation," AAS Astrodynamics Specialist Conference, Providence, Rhode Island, Aug. 16–19, 2004. Paper No. 04-5213.
6. G. G. Parker, C. Passerello, and H. Schaub, "Static Formation Control Using Interspacecraft Coulomb Forces," 2nd International Symposium on Formation Flying, Washington, D.C., Sept. 14–16, 2004.
7. J. Berryman and H. Schaub, "Static Equilibrium Configurations in GEO Coulomb Spacecraft Formations," AAS Spaceflight Mechanics Meeting, Copper Mountain, CO, Jan. 23–27, 2005. Paper No. 05-104.
8. A. Natarajan and H. Schaub, "Linear Dynamics and Stability Analysis of a Coulomb Tether Formation," AAS Spaceflight Mechanics Meeting, Copper Mountain, CO, Jan. 23–27, 2005. Paper No. 05-204.
9. D.Izzo and L.Pettazzi "Equilibrium shaping: distributed motion planning for satellite swarm", accepted for the 8th International symposium on Artificial Intelligence, Robotics

and Automation in Space, Munich, Germany, 2005.

10. M.Ayre, D.Izzo, L.Pettazzi "Self Assembly in Space Using Behaviour Based Intelligent Components" accepted at TAROS 2005, Towards Autonomous Robotic Systems Imperial College, London, UK. 12-14 September 2005.
11. C.R.McInnes, "Potential Function Methods For Autonomous Spacecraft Guidance and Control", Paper AAS 95-447, 1995.
12. M.A.Peck, "Prospects and Challenges for Lorentz-Augmented orbits" in preparation, available on-line.