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Author: Dr. Lorenzo Marchionne
Sapienza University of Rome, Italy, marchionne.1692965@studenti.uniroma1.it

Dr. Darren McKnight
LeoLabs, United States, darren@leolabs.space
Prof. Fabio Santoni
Sapienza University of Rome, Italy, fabio.santoni@uniroma1.it
Mr. Christophe Bonnal
Centre National d'Etudes Spatiales (CNES), France, christophe.bonnal@cnes.fr
Dr. Fabrizio Piergentili
Sapienza University of Rome, Italy, fabrizio.piergentili@uniroma1.it

CONCEPTUAL DESIGN AND PERFORMANCE ANALYSIS OF NANO-TUGS AS A SPACE DEBRIS REMEDIATION TOOL

Abstract

The growth of debris population will be largely driven by collisions between massive derelict objects (i.e., abandoned rocket bodies and defunct payloads). The traditional proposed approach to reducing the possibility of such an event is Active Debris Removal (ADR) whereby a large object is grappled, detumbled, and moved onto a re-entry trajectory. Due to the enormity of many of these objects (1,000 to 9,000 kg), ADR operations will be taxing and re-entry hazard will be significant. As a matter of fact, it is likely that all of the objects with mass greater than 1,000 kg will require controlled re-entry to adhere to ground safety thresholds. This requirement will add even more stringent design needs to the ADR solution. ADR remediates the collision risk of massive derelicts by removing them from orbit, however, another remediation option is to simply prevent the derelicts from colliding without removing them from orbit. While there are two remediation options in addition to ADR that prevent massive objects from colliding, such as Just-in-time Collision Avoidance (JCA) and Large Debris Traffic Management (LDTM), this paper examines a third alternative called a Nano-tug. It is proposed that one or more nanoSats be deployed as a cooperative swarm to attach to massive derelicts. A Nano-tug has, at a minimum, grappling mechanism, electric propulsion system, attitude determination and control system, and Global Positioning System(GPS) receiver. This combination enables the detumbling and stabilization of the derelict; creates a position determination function for the derelict; and provides collision avoidance capability. The derelict is thus transformed from debris into part of the space traffic whose safety is managed through the expanding Space Traffic Management (STM) constructs. Engineering designs that support the requirements of a Nano-tug are reviewed and potential technological solutions are discussed. Key engineering parameters are identified and characterized: attachment mechanism, command control systems, maximum possible encounter velocity, power source, number of Nano-tugs needed, type of propulsion system, etc. Performance specifications of state-of-the-art components are used to examine the Nano-tug solution and propose a conceptual design. Finally, control schemes are synthesized for the critical maneuvers in the mission, namely, (i) rendezvous for approaching and attaching to the debris, including concurrent Nano-tug position/attitude control (ii) detumbling maneuver for stabilizing the debris attitude motion, (iii) collision avoidance maneuver, and (iv) attitude stabilization strategy during stand-by phases between collision avoidance maneuvers. Several numerical simulations verify and validate the proposed approach and the control schemes.