論文の内容の要旨

Cluster Flight Orbit Design and Control for Fractionated Spacecraft

（機能分散型複数衛星システムのための群飛行軌道の設計と制御に関する研究）

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The fractionated spacecraft system, also called system F6 (Future Fast, Flexible, Fractionated, Free-Flying Spacecraft united by Information exchange) is a satellite architecture where the functional capabilities of a conventional spacecraft are distributed across multiple modules that fly separately and interact through wireless links. Among many key technologies provided by fractionated spacecraft, the cluster flight technology is the most important one and should be fully studied. Different from the extensively studied formation flying technology, cluster flight is a new problem, hence, novel guidance and control approaches need to be presented. In order to propose feasible and reliable cluster flight relative orbit design and control approaches, the following challenging research topics are fully investigated and addressed in this PhD thesis.

1. Presented Fuel-optimal cluster flight orbit design approach

Cluster flight orbit design issue is the problem regarding to how to deploy several member satellites in cluster to satisfy various objectives (fuel-optimal) and constraints (passive safety and maximum inter-satellite distances) determined by the concept of fractionated spacecraft, to solve which, the Genetic Algorithm (GA) is presented. Firstly, the cluster flight orbit design problem is formulated as a constrained optimization problem in terms of relative eccentricity/inclination vectors (E/I vectors), and then the GA method is adopted to solve it. Finally, several numerical simulations are conducted to provide the selection criterions for key design parameters. Numerical simulation results show that the proposed GA based fuel-optimal cluster flight orbit design method is effective, and the design solution obtained by GA method all satisfy passive safety and maximum distance constraints defined by cluster missions.

2. Proposed Fuel-optimal and fuel-balanced cluster relative geometry maintenance strategies

Due to disturbances and perturbations in orbit, designed cluster relative orbit will drift away. Therefore, relative orbit keeping method with fuel-optimal and fuel-balanced features is needed. To overcome the shortcomings caused by the method derived by K.T. Alfriend, two creative cluster relative geometry keeping strategies are proposed. First, better fuel consumption performance is achieved by reformulating relative geometry maintenance problem in terms of relative E/I vectors by considering both in-plane and out-of-plane J2 perturbations. Second, for member satellite in different relative orbit scenario, we proposed a method by controlling each satellite with respect to an optimal virtual center. The center was selected in terms of relative E/I vectors in a fuel-optimal and fuel-balanced sense and fully verified by numerical simulations. The cluster flight keeping method based on virtual center selection can deal with the cluster keeping problem with member satellites in different relative orbits and can achieve better fuel consumption performance than Alfriend's method for some certain cluster flight missions.

3. Derived optimal cluster reconfiguration strategy based on relative orbital elements

Cluster reconfiguration pertains to the scenario in which the cluster needs to reconfigure from one existing cluster to another desired cluster in case of changing mission requirements or the addition of member satellite. To overcome the disadvantages caused by numerical methods, it is essential that analytical solutions should be found. To propose an analytical cluster reconfiguration strategy, we formulated the problem in a relative orbital elements sense, and reparameterized it as the optimal maneuver problem for relative E/I vectors, which was solved in the relative E/I vector plane with a geometrical proof using triangle inequalities. Based on our method, given a set of transfer conditions, it is easy to obtain the optimal fuel consumption and analytical fuel-optimal impulsive reconfiguration control sequence. The analytical relative orbit transfer method can solve cluster reconfiguration issue involving member satellite assignment problem, which is very convenient for on board application.

4. Presented failure scenarios based collision avoidance control strategies for cluster flight

Traditional collision avoidance strategies have difficulties to address potential collisions caused by satellite failure, for the reason that two important issues are missing, namely, collision prediction to predict future collisions and failure scenarios based collision avoidance control strategies corresponding to various possible failures. In order to propose failure scenarios based collision avoidance control strategies, one collision prediction algorithm and the failure scenarios based collision avoidance control strategies are proposed as: for short term and long term recoverable failure cases, the failure satellites will be controlled to their normal orbits, but, for short term and long term unrecoverable failure cases, instead to control the failure satellite back to normal formation configuration, the formation will be controlled to one new collision free configuration with passive safety characteristic obtained by GA method. The validities of the failure scenarios based collision avoidance control strategies are confirmed by numerical simulations.