ASTRODYNAMICS SYMPOSIUM (C1)
Guidance, Navigation & Control (3) (5)

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A DECENTRALIZED AND AUTONOMOUS FORMATION PLANNING ARCHITECTURE OF LARGE-SCALE SPACECRAFT SWARM USING ARTIFICIAL POTENTIAL FIELD AND BIFURCATION DYNAMICS

Abstract

When it comes to increasingly complex deep space mission detection demand and new observations, spacecraft swarm technology, with its flexible deployment, fast response, and reconfigurability, has become one of the spotlight fields. Traditionally, the relative formation control between spacecraft mainly relies on the centralized control architectures, such as Leader/Follower or Virtual Structure Coordination, which require the centralized path planning of each agent in the swarm. The disadvantage of centralized architectures is that as the number of spacecraft in the swarm increases, the control computational workload required to keep a formation discretely and maintenance cost of the swarm system will increase significantly to an infeasible level and controlling the swarm formation in a centralized way becomes unrealistic, and may even cause system unstable. In this paper, an autonomous and decentralized formation planning method for large-scale spacecraft swarm is developed to accomplish different formation topologies and reconfiguration using only one simple control law. The nonlinear dynamic system bifurcation theory together with artificial potential field method is applied. Artificial control force field is designed so that the system has desired bifurcation and stability characteristics to achieve different formation configurations or formation reconfiguration. Static and dynamic bifurcating artificial potential fields are constructed through using hyperbolic-exponential function and a unique Hopf bifurcation function respectively to accomplish static and dynamic formation. The stability of the formation is verified through theoretical proof using Lyapunov method and local linearization method. In addition, the linear coordinate transformation and redefining of the relative position vector are introduced to generate non-spherically symmetrical potential field so as to realize formation distortion and some non-uniform formations. Different cases of formation flying of swarm with 30 spacecraft are simulated. The preliminary results show that the proposed method can achieve many different formation configurations, such as single circle and ellipse, double concentric circle and ellipse, disc and elliptical disc, diamond, etc. Decentralized and autonomous spacecraft swarm formation planning is achieved through the use of an artificial bifurcating potential function method. Through dynamic system theory, a simple parameter change with bifurcation phenomena arising can make a large-scale spacecraft swarm formation to alter its configuration and size. Each spacecraft moves cooperatively with all the other spacecraft “naturally”, without direct communication between each other and any extra external orders or guiding and centralized planning and control. Rather

than controlling each spacecraft individually, the global configuration of the formation can be controlled via the bifurcation parameter.