

A Prognostics Framework Development for Swarm Satellite Formations

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Prognostics is the science of predicting the failure(s) of a component or a system and understanding how the performance will change in the event of a failure or degradation mechanism. With accurate predictions of possible failures, autonomous mitigative actions can be taken to correct/repair any issues or alert human operators of a failure threshold exceedance requiring condition-based maintenance. Although there is extensive research on failure predictions for a component or a system, there are significantly more opportunities to foray into failure predictions and prognostics for a system of systems such as an airspace consisting of multiple aircraft, a fleet of unmanned aerial vehicles, and a swarm of intelligent satellite systems. Failure prediction and mitigation are particularly important in autonomous systems such as swarms satellite systems that need effective resource management and minimal human interactions.

Based on NASA's decadal survey, there is a clear need to prioritize the development of satellite swarm technology for studies of space physics and Earth science. The science community will propose future missions that return in-situ measurements from a 3-D volume of space, with relative spacecraft motion and inter-satellite baselines controlled according to the mission objectives. For such multi-spacecraft missions, it is required that ground operations resources do not scale with the number of satellites, thus compromising the swarm or leading to inefficiencies in resource allocation. Swarms of tens or hundreds of small satellites will require autonomy in attitude control, navigation and failure. Although significant research has been conducted in the areas of autonomous formation flying algorithms, less attention has been given to the development of resilient systems robust to failures.

The focus of this research paper is the integration of model-based prognostics into the swarm dynamics control and decision-making algorithms. We simulate swarm management strategies for a subsystem failure to demonstrate the importance of failure predictions by comparing two cases: (i) no health information is provided to the system and utilized in the decision-making process and (2) system health information is obtained using prognostics and employed by the control system. One example scenario presented is for the GPS system of an individual satellite to perform off-nominally due to increasing estimated error. In this scenario, the "keep-out zone" for that satellite would become more conservative, thereby decreasing the risk of collision. This is achieved via tuning the individual artificial repulsive functions assigned to each satellite.

This paper is structured as follows. First we provide an overview of current swarm technology development, where we specifically use the term *swarm* to define multiple satellites flying in formation in similar orbits, with cross-link communication and station-keeping capabilities. Second, we give an introduction to the Swarm Orbital Dynamics Advisor (SODA), a tool that accepts high-level configuration commands and provides the orbital maneuvers required to achieve the prescribed formation configuration. Third, we provide the details of the model-based prognostics algorithm implementation in SODA. Finally, we present different case studies for potential component/subsystem failures and the swarm responses based with and without failure prediction information.