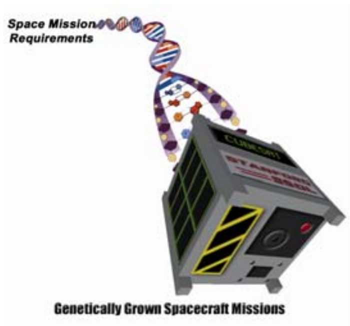
Using Genetic Algorithms to Maximize Utility of Constrained Space Systems for Improved Mission Design and Performance



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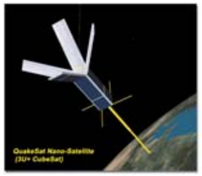
Abstract

CubeSat projects such as Stanford University's QuakeSat nano-satellite have demonstrated that small satellites are a viable platform for conducting scientific research and space experimentation. Nevertheless, in order to accomplish more scientifically valuable and tech-nically sophisticated space missions, the utility, that is the level of how well the system design meets its overall mission objectives, must first be dramatically increased. This is largely due to the fact that small satellites, such as CubeSats are typically subject to a greater number constraints such as limited size, surface are, peak power, attitude control, and orbit types, which can fundamentally restrict the performance parameters of the system compared to larger, more robust satellites.



It is anticipated, however, that over time advances in miniaturized satellite components and subsystems will enable CubeSats to be more technically advanced small satellites. Nevertheless, the fundamental question remains, what is the minimal level of capability or risk that either optimizes or achieves sufficiently high level of performance such that the requirements of the mission are met?

Genetic algorithms are one potentially valuable methodology for increasing space mission utility since they can be highly effective in searching the span of the trade space in order to identify promising candidate mission architectures.

Introduction

Genetic algorithms employ a probabilistic search algorithm that is capable of spanning a search space. Based on the concept of survival of the fittest, genetic algorithms iteratively transform and evaluate a given population using a fitness function, which enables successive new generations of the population to be produced with improved characteristics. In the context of spacecraft design with genetic algorithms, a population of mission concepts is used and the fitness function is derived from the set of mission requirements.

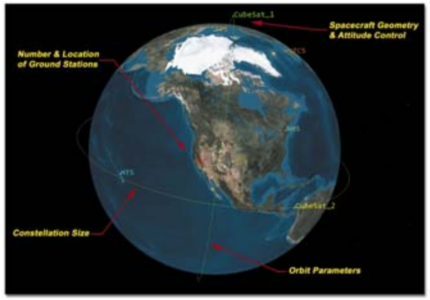
This technique enables a systematic approach to exploring a vast number of diverse mission concepts and identifies optimized solutions and even non-intuitive design options, which meet the required mission objectives.

Using genetic algorithms, space mission architecture elements such as orbit parameters, constellation size, spacecraft geometry, method of spacecraft attitude control, and the number and location of ground stations are varied and explored in accordance to the mission requirements and constraints.

Methods & Materials

The essential components required are: Matlab/Simulink, Satellite Tool Kit (STK), and the STK/Matlab Interface.

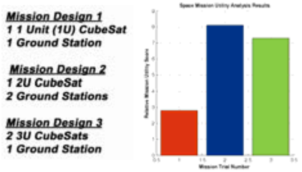
Matlab is the core the analysis engine that is used to generate candidate mission populations, evaluate the fitness of a population, and quantify the utility of the mission candidate after simulation is complete. STK is the space mission simulation tool that is used to test the performance of the overall mission architecture. Lastly, the interchange of data between the two major components is achieved using the STK/Matlab Interface.



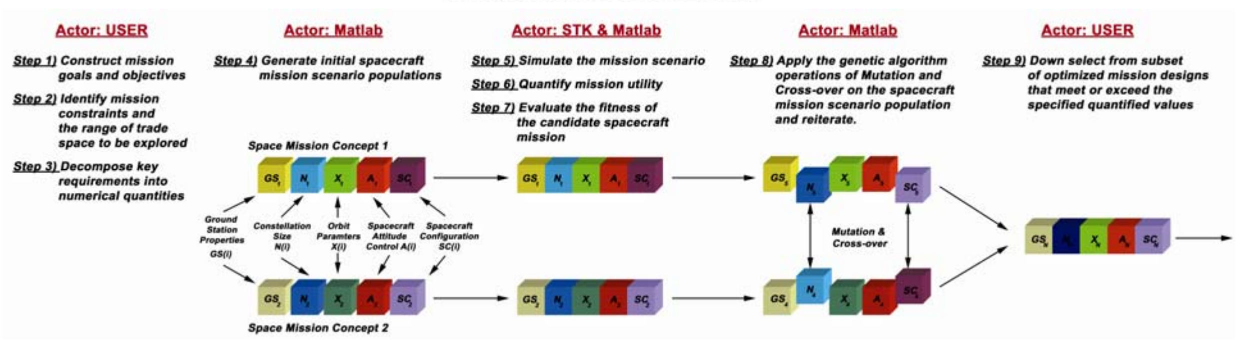
Results

At the current stage in my research, I am performing the object oriented design of the data structures that enable the abstraction of space mission architectures to be extensible and able to be integrated into a genetic algorithm framework.

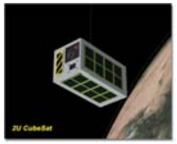
Nevertheless, the capability of running a simulation of a mission concept, and quantifying mission utility has been completed. As a demonstration, three mission concepts were explored for an example satellite mission, FireSat. With the primary objective of being able to detect forest fires within all the fifty states and furthermore being able to report the detection of such fires to fire fighters within a half an hour was run. In each scenario, different spacecraft mission architecture with different sized CubeSat satellites was run. The mission utility results of each mission in are shown below.



Utility Maximization Process



Conclusions



Quantifying the utility of a space mission is essential in the design phase since it provides valuable information to both the space mission designers and to the decision makers.

In the FireSat example, the first space mission architecture is the least capable of meeting the primary mission requirement. The second architecture, resulted the highest combined utility since it is able to communicate detection information within the required time period. The third mission architecture, however, is able to provide the greatest amount of area coverage, but is not able to report forest fire detections within the required time.

This simple example illustrates that a spacecraft is just one part of the overall mission picture. Both the concept of operations (ConOps) and spacecraft capability are key elements in the design. As a result, mission utility is ultimately a function of these two fundamentals.

Given a set of mission constraints and requirements, the value added by using genetic algorithms in space mission design is that the utility of a vast number of mission architectures can be explored. Down selection from subset of highly optimized mission utility designs can then be performed in accordance with overall mission

and schedule.