Intelligent Satellite Teams for Space Systems

Position Paper

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Abstract

We examine the development of Intelligent Satellite Teams (IST's) for complex space missions such as construction of space hardware, or Earth or space science. IST's are composed of many *nanosatellites* (mass < 1kg) or *picosatellites* (mass < 1g). IST development is a synergy of many disciplines, such as: *intelligent control* including formation flying, collision avoidance, knowledge sharing, and adaptive reconfiguration; *microtechnology* including microelectromechanical systems (MEMS), microfabricated sensors and actuators, nanotechnology, and integrated wireless communication; *mission analysis* – high-level planning and control of mission, satellites, and procedures. Recent rapid technological advances in these fields open up exciting new possibilities for future space missions. The long-term goal of this project is to combine these advances to devise a systems-level approach for the construction of IST's. Candidate missions include construction or servicing of space facilities such as space laboratories or telescopes; measurement of an asteroid's gravitational field using hundreds of picosatellites, and reconfiguration into phased antenna arrays for communication back to Earth. In this paper, we discuss the specific requirements for Intelligent Satellite Teams and describe sample missions in an ongoing feasibility study for IST's with focus on intelligent control. The goal of this work is to develop design prototypes for intelligent teams of nano and pico satellites.

Introduction

Two technologies whose future potential will revolutionize IST's for a wide variety of missions are autonomy obtained from increased on-board intelligence, and the small size, mass, and modularity of MEMS devices. When combined, these technologies will provide fundamentally new possibilities in low-cost, distributed, redundant spacecraft and space missions.

Background and Related Work

The concept of nano and pico satellites has gained growing popularity. Various efforts are currently underway to miniaturize spacecraft components. For example, MEMS researchers are investigating techniques for micro-propulsion and formation flying for miniature satellites. However, teams of satellites also pose formidable new challenges, especially in terms of autonomy. How can large numbers of satellites (each of them possibly with very limited resources) be controlled efficiently? Key technologies will include advances in architectures and algorithms for autonomous agents, and for distributed control and intelligence.

Currently, AI based software is being developed for robots, unmanned vehicles, and spacecraft. As an example, The Deep Space 1 mission was supposed to be the first demonstration of the use of agents onboard a spacecraft. During the mission, the spacecraft is sent a list of goals instead of the usual detailed sequence of commands to execute. The Remote Agent software generates a plan to accomplish these goals and then execute this plan, looking out for hardware faults during execution. If any occur, the RA takes recovery actions. Unfortunately, prior to launch, most of the RA software on DS-1 was replaced by conventional Mars Pathfinder software due to development problems.

Requirements for IST's

While nano and pico IST's pose challenges in various disciplines, we focus here on their autonomy and control architecture. It must be able to

- encode mission goals into the fleet (*autonomy*)
- utilize many satellites for fault tolerance (*redundancy*)
- easily integrate higher performance goals, e.g. formation flying (*collective behavior*)
- integrate decision making, reconfiguration, and learning into the fleet (*adaptation*).

System Architecture

Consider a mission of mapping out another planet while in orbit. Using hundreds of nanosats in an IST would be an excellent choice, but how would the mission objectives be solved? Consider this sequence of events:

- On the ground, the support person relays the objective of mapping the "peaks" of the planet.
- A group of "leader sats," getting the message from the ground station, then proceed to evaluate where the peaks are, and what current satellites are near them.

- The "leader sats" then coordinate groups of satellites of the IST to image the peaks, scheduling and planning each of the satellites' duties.
- Within each satellite, once the commands are received from the "leader sats," the decision must be made as to what each subsystem must do and when.
- As satellites orbit the planet, each satellite's duties change as they see different targets. "Leader sats" coordinate how information is passed between the satellites, and how duties are handed off.
- If one or more satellites (and/or their subsystems) become damaged and are unable to perform their duties, the "leader sats" must evaluate the problem and develop a contingency plan.

There are of course many other additions and variations to this sequence. With this information, an AI-based architecture is envisioned as enabling for the above sequence of events. It can be a layered approach of agents at three different levels, as shown below.

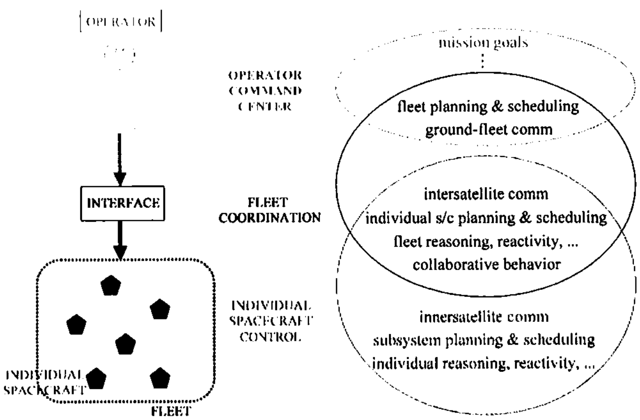

Figure 1: Flow of high-level mission objectives within the fleet (IST) and spacecraft subsystem.

Sample Missions

In the remainder we describe two typical missions for IST's that require various levels of on-board intelligence and the ability to learn.

Space Construction

Consider using tens of nanosatellites in an IST. The IST could be coordinated to build or service a space facility. Plans for a new space facility are drawn up electronically, including parts and supplies, and inserted into precision robotic nanosatellites. The launch vehicle is used, possibly with modular supplies built into the vehicle. Once in orbit, the nanosatellites are deployed and coordinate in an IST, as shown in Figure 2. Precision robotic satellites (specialized workers) are deployed autonomously using collective intelligence, and work on a specific portion of the facility. A leader satellite can be used to supervise construction and relay information to human operators on Earth, or the robotic satellites can be reconfigured into an antenna for communication. Supply satellites are also used. At the end of construction, the IST could then be reconfigured for another effort in support of the space facility.

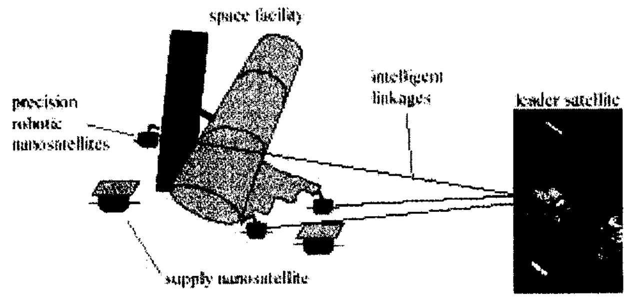

Figure 2: Concept of Intelligent Satellite Teams (IST's) for space construction.

Asteroid Exploration

While autonomy is an important aspect for IST's of tens of nanosats, the small size, mass, and modularity of MEMS devices opens up new possibilities for IST's with hundreds or even thousands of smaller picosats. Very large quantities (~1M or more) of picosats can be loaded onto a conventional launch system, transported to a target location and then released. Furthermore, MEMS devices are (a) extremely strong and can withstand many thousands of g's of acceleration, (b) very light (mg or less). Motivated by hundreds of picosats in an IST, a second concept focused on a science mission is currently being investigated. Many picosats can be fabricated in a batch process, and launched toward an asteroid or other science object. Once in orbit, the IST organizes itself in a grid of nodes, gathers science information, and shares it amongst the other members of the IST (Figure 3).

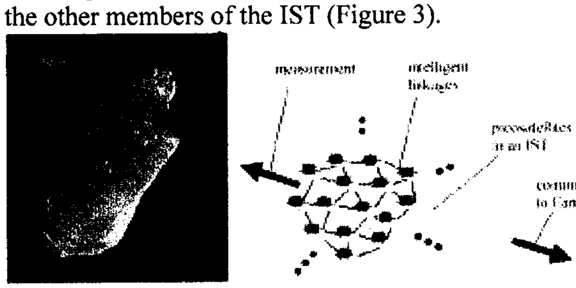

Figure 3: Concept of IST's for space science and communication.

For example, detected changes of relative position of the picosats due to the asteroid's gravity give a measurement that is very difficult to obtain by other means. Then, by reconfiguring the IST, communication with Earth is simplified by using the IST as an antenna array.

Acknowledgements

This work is part of a Phase I study for the NASA Institute for Advanced Concepts (NIAC).