DEMO: Autonomous Science Analysis, Planning, and Execution on the EO-1 Mission

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Abstract

In 2003, the Earth-Orbiting One (EO1) spacecraft will demonstrate several integrated autonomy software technologies to enable autonomous science. The Autonomous Sciencecraft Experiment (ASE) software will demonstrate the potential for future space missions to use onboard decision-making to detect science events and respond autonomously to capture short-lived science events and to downlink only the highest value science data. The ICAPS software demonstration will consist of a typical EO1 scenario using this autonomy software.

Introduction

The ASE [Chien et al., 2001] will use several science algorithms to analyze science data including: onboard event detection, feature detection, change detection, and unusualness detection. These algorithms will be used to downlink science data only on change, and will detect features of scientific interest such as volcanic eruptions, sand dune migration, growth and retreat of ice caps, and crustal deformation. These onboard science algorithms are inputs to onboard decision-making algorithms to modify the spacecraft observation plan to capture high value science events. This new observation plan will then be executed by a robust goal and task oriented execution system, able to adjust the plan to succeed despite run-time anomalies and uncertainties. Together these technologies enable autonomous goal-directed exploration and data acquisition to maximize science return.

Autonomy Software Architecture

The autonomy software on EO-1 is organized into a traditional three-layer architecture. At the highest level of abstraction, the Continuous Activity Scheduling Planning Execution and Replanning (CASPER) system is responsible for mission planning functions. CASPER schedules science activities while respecting spacecraft operations and resource constraints. For EO-1, CASPER operates on the tens of minutes timescale. CASPER scheduled activities are inputs to the Spacecraft Command Language (SCL) system, which is responsible for the detailed sequence commands corresponding to CASPER scheduled activities.

SCL operates on the several second timescale. Below SCL the EO-1 flight software is responsible for lower level control of the spacecraft and also operates a full layer of independent fault protection. The interface from SCL to the EO-1 flight software is at the same level as ground generated command sequences. The science analysis software is scheduled by CASPER and executed by SCL in batch mode. The results from the science analysis software result in new observation requests presented to the CASPER system for integration in the mission plan.

Onboard Science Analysis

The first step in the autonomous science decision cycle is detection of science events of interest. In the complete experiment, a number of science analysis technologies will be flown including thermal anomaly detection, cloud detection, flood scene classification, change detection, feature detection, and anomaly detection. Three of these algorithms will be shown in the demonstration.

Onboard Mission Planning

In order for the spacecraft to respond autonomously to the science event, it must be able to independently perform the mission planning function. This requires software that can model all spacecraft and mission constraints. In the EO-1 Experiment, this function is performed by the CASPER [Chien et al., 2000] software. CASPER represents the operations constraints in a general modeling language and reasons about these constraints to generate new operations plans that respect spacecraft and mission constraints and resources. CASPER uses a local search approach [] to develop operations plans.

CASPER is responsible for long-term mission planning in response to both science goals derived onboard as well as anomalies. In this role, CASPER must plan and schedule activities to achieve science and engineering goals while respecting resource and other spacecraft operations constraints. For example, when acquiring an initial image a volcanic event is detected, CASPER plans a response. This event may warrant a high priority request for a subsequent image of the target to study the evolving phenomena. In this case, CASPER will modify the operations plan to include the necessary activities to re-image. This may include determining the next over flight opportunity, ensuring that the spacecraft is pointed appropriately, that sufficient power, and data storage are available, that appropriate calibration images are acquired, and that the instrument is properly prepared for the data acquisition.

Onboard Robust Execution

EO-1 will fly the Spacecraft Command Language (SCL) [SCL Web Page] to provide robust execution. SCL is a software package that integrates procedural programming with a real-time, forward-chaining, rule-based system. A publish/subscribe software bus allows the distribution of notification and request messages to integrate SCL with other onboard software. This design enables either loose or tight coupling between SCL and other flight software as appropriate.

The SCL "smart" executive supports the command and control function. Users can define scripts in an English-like manner. In the EO-1 demo, SCL scripts will also be planned and scheduled by the CASPER onboard planner. The science analysis algorithms and SCL work in a cooperative manner to generate new goals for CASPER. These goals are sent with a messaging system.

Description of Demonstration Scenario

The software being demonstrated includes the CASPER planning and scheduling software, the Spacecraft Command Language (SCL) execution software, the EO1 simulation software, the cloud cover detection algorithm, the thermal anomaly algorithm, and the change detection algorithm. These software programs communicate through a message passing architecture.

The demonstration scenario includes the following:

- At the start of the demo, a simulator of the EO1 spacecraft is started. This simulator includes the EO1 dynamics, instruments, subsystem initial states, and commands. The planner is started with an initial set of goals that include imaging activities of the Kansas City area, a bay in Antarctica, and the Mt. Etna volcano in Italy.
- The first science goal is executed by taking an image of Kansas City. The cloud detection algorithm runs and determines that the cloud coverage in the scene is greater than the set threshold. Scenes with high cloud coverage have a low science value because the ground is obscured. Therefore the image is discarded. As a result of the image being discarded, the spacecraft now has additional memory and downlink time available. These are scarce resources for EO1. As a result, the planner will try to add another imaging activity from the onboard list of goals, in hopes of capturing a clear view of the target and replacing the cloudy image. This new request is sent to CASPER, which has the job of expanding the request into a detailed sequence of spacecraft commands. These commands must be scheduled at the correct times, and with the correct parameter values, to ultimately collect, store, and downlink the requested science data. When generating these commands, CASPER must also respect spacecraft hardware and safety constraints. For example, to prevent contamination and/or damage to the instruments, the instrument covers must be closed during a spacecraft slew. To avoid loss of data, the on-board recorder must have enough free space to accommodate the image and associated calibration data. More importantly, the recorder could be damaged if commanded to read and write at the same time. All of these constraints have been encoded in CASPER's model used when generating command sequences.
- The new imaging goal that CASPER inserted into the plan is for Cheyenne, Wyoming. The planner expands the goal into activities that result in commands to acquire the image. The commands are sent to the SCL executive, the image is acquired and run through the cloud detection algorithm. The cloud detection algorithm determines that this image has a 27% cloud cover. This image is below the threshold of cloud coverage and therefore has a high science value. The image is forwarded to the queue to be downlinked at the next opportunity.
- The next image that was planned by CASPER was of an area in Antarctica where the ice shelf may be experiencing dynamic change. CASPER sends the commands to SCL to image this area and run a change detection algorithm on this image and previous image of the same area. The change detection algorithm detects a significant change and therefore this image is placed into the queue for downlink. Had no change been detected, this image would have been discarded.
- The next image that was planned was of a potentially active volcano, Mt Etna in Italy. CASPER sends the commands to SCL to image this area in 2 different spectral bands (visible and IR). Both the visible and IR scenes show clouds. The science module is run using a thermal anomaly detector. Several new lava flows are seen. A new goal is generated to image this area on a subsequent orbit in order to track these fast moving phenomena.

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