DEMO: The Autonomous Sciencecraft Experiment Onboard the EO-1 Spacecraft

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Abstract

The Autonomous Sciencecraft Experiment (ASE), currently flying onboard the Earth Observing-1 (EO-1) spacecraft, integrates several autonomy software technologies enabling autonomous science analysis and mission planning. The experiment demonstrates the potential for future space missions to use onboard decision-making to respond autonomously to capture short-lived science phenomena. The software demonstration will consist of two sections: a real-time display of an ASE-commanded ground contact from the EO-1 spacecraft, and a simulation of the full ASE autonomous science-response scenario.

Introduction

The Autonomous Sciencecraft Experiment (ASE) [Chien et al., 2003] is currently flying onboard NASA's Earth Observing-1 (EO-1) spacecraft. Uploaded in the Fall of 2003, ASE has successfully commanded EO-1 operations and enabled autonomous retargeting to capture dynamic science events. ASE is currently executing a series of ambitious science-response scenarios scheduled for completion in the Fall of 2005. The ASE onboard flight software includes several autonomy components:

1. *Onboard science processing algorithms.* Science analysis algorithms process onboard image data to detect science events and suggest reactions to maximize science return.
2. *Onboard planning and scheduling software.* The Continuous Activity Scheduling Planning Execution and Replanning (CASPER) [Chien et al., 2000] system generates mission operations plans from goals uplinked by the EO-1 Science Team or inserted by the onboard science analysis module. The model-based planning algorithms enable rapid response to a wide range of operations scenarios based on models of spacecraft constraints.
3. *Robust execution software.* The Spacecraft Command Language (SCL) expands the CASPER mission plans to low-level spacecraft commands. SCL monitors the execution of the plan and has the flexibility and knowledge to perform improvements in execution as well as local responses to anomalies.

Building autonomy software for space missions presents a number of key challenges:

1. *Limited, intermittent communications.* EO-1 has eight ten-minute communications opportunities per day. This means that the spacecraft must be able to operate for long periods of time without supervision.
2. *Complex subsystems and controls.* A typical spacecraft has thousands of components carefully engineered to survive the rigors of space.
3. *Limited observability.* Bandwidth and onboard processing constraints limit the availability of engineering telemetry. Onboard software and ground operations teams must be able to operate the spacecraft on limited information.
4. *Limited computing resources.* An average spacecraft CPU offer 25 MIPS and 128 MB RAM – far less than a typical personal computer. The EO-1 team allocated 4 MIPS for all of the ASE software.
5. *High stakes.* A typical space mission costs hundreds of millions of dollars, any failure has significant economic impact.

ASE on EO-1 demonstrates an integrated autonomous mission using onboard science analysis, replanning, and robust execution. ASE performs intelligent science data processing, editing, and spacecraft retargeting, leading to a reduction in data downlinked and an increase in science return. These capabilities enable radically different missions with significant onboard decision-making allowing novel science opportunities. The paradigm shift toward highly autonomous spacecraft will enable future

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NASA missions to achieve significantly greater science returns with reduced risk and reduced operations cost.

Live ASE Contact from EO-1

The first part of the demonstration will showcase a live contact from the EO-1 spacecraft *commanded onboard by ASE*. Telemetry from the spacecraft will be displayed remotely from the EO-1 Mission Operations Center at Goddard Spaceflight Center. The real-time telemetry stream will display the commands currently executing onboard EO-1 and the status of each ASE software component. During the demonstration ASE will downlink engineering and science data by issuing spacecraft commands to achieve the following objectives:

1. Point the X-Band phased-array antenna at the groundstation one minute prior to acquisition of signal (AOS).
2. At AOS, power on both transceivers and configure S-Band for a 2 Mbit downlink rate.
3. Command the onboard solid state recorder to playback mode and begin streaming science data over the X-Band link.
4. Initiate the dumping of engineering data over S-Band.
5. Initiate the playback of the spacecraft event log through S-Band.
6. At loss of signal (LOS), turn off the S-Band transceiver, stop streaming science data, and begin streaming fill data.
7. Ten seconds after LOS, power down the X-Band transceiver and return the solid state recorder to standard operations mode.

A typical EO-1 contact lasts between 10 and 15 minutes.

Full Autonomous Science Scenario

The second part of the demonstration will simulate an ASE mission scenario. During this demonstration ASE will command a software simulation of the EO-1 spacecraft to image science targets, process and analyze onboard image data, and re-plan operations based on science results.

The demonstration will highlight the following capabilities of ASE:

1. *Autonomous Execution*. CASPER will generate a mission plan using an uplinked set of high-level goals requesting science observations and data downlinks. SCL will convert these plans to sequences of spacecraft commands and issue these commands to EO-1.
2. *Dynamic Event Tracking*. The onboard science analysis algorithms will detect an erupting volcano in one of the requested observations, and as a result recommend a follow-on observation.
3. *Data Editing*. During the analysis of another science observation, the analysis algorithms will determine an unacceptable percentage of cloud-obscured data. Based on this analysis the ASE software will recommend deleting this image and imaging an alternate target.
4. *Onboard Replanning*. CASPER will modify the onboard schedule to respond to the science analysis recommendations to insert new observations and delete low-value data from onboard storage.

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