Software

Autonomous Coordination of Science Observations Using Multiple Spacecraft

This software provides capabilities for autonomous cross-cueing and coordinated observations between multiple orbital and landed assets. Previous work has been done in re-tasking a single Earth orbiter or a Mars rover in response to that craft detecting a science event. This work enables multiple spacecraft to communicate (over a network designed for deep-space communications) and autonomously coordinate the characterization of such a science event.

This work investigates a new paradigm of space science campaigns where opportunistic science observations are autonomously coordinated among multiple spacecraft. In this paradigm, opportunistic science detections can be cued by multiple assets where a second asset is requested to take additional observations characterizing the identified surface feature or event. To support this new paradigm, an autonomous science system for multiple spacecraft assets was integrated with the Interplanetary Network DTN (Delay Tolerant Network) to provide communication between spacecraft assets.

This technology enables new mission concepts that are not feasible with current technology. The ability to rapidly coordinate activities across spacecraft without requiring ground in the loop enables rapid reaction to dynamic events across platforms, such as a survey instrument followed by a targeted high-resolution instrument, as well as regular simultaneous observations.

This work was done by Tara A. Estlin, Steve A. Chien, Rebecca Castano, Daniel M. Gaines, Joshua R. Doubleday, Joshua B. Schoolcraft, Amalaye Oyake, Ashton G. Vaughs, and Jordan L. Torgerson of Caltech and Charles de Granville for NASA's Jet Propulsion Laboratory. For more information, contact iaoffice@jpl.nasa.gov.

This software is available for commercial licensing. Please contact Daniel Broderick of the California Institute of Technology at danielb@caltech.edu. Refer to NPO-47398.

Autonomous Phase Retrieval Calibration

The Palomar Adaptive Optics System actively corrects for changing aberra-

tions in light due to atmospheric turbulence. However, the underlying internal static error is unknown and uncorrected by this process. The dedicated wavefront sensor device necessarily lies along a different path than the science camera, and, therefore, doesn't measure the true errors along the path leading to the final detected imagery. This is a standard problem in adaptive optics (AO) called "non-common path error."

The previous method of calibrating this error consisted of manually applying different polynomial shapes (via actuator voltages) at different magnitudes onto the deformable mirror and noting if the final image quality had improved or deteriorated, before moving onto the next polynomial mode. This is a limited, time-consuming, and subjective process, and structural and environmental changes over time necessitate a new calibration over a period of months.

The Autonomous Phase Retrieval Calibration (APRC) software suite performs automated sensing and correction iterations to calibrate the Palomar AO system to levels that were previously unreachable. APRC controls several movable components inside the AO system to collect the required data, automatically processes data using an adaptive phase retrieval algorithm, and automatically calculates new sets of actuator voltage commands for the deformable mirror. APRC manages and preserves all essential data during this process.

The APRC software calculates the true wavefront error of the full optical system, then uses the existing AO system deformable mirror (DM) to correct the detected error. This provides a significant leap in performance by precisely correcting what were once "un-calibratable" errors. Furthermore, the corrective pattern found by this process serves as the underlying nominal shape of the DM, upon which the adaptive corrections for atmospheric turbulence are based.

This work was done by Siddarayappa A. Bikkannavar, Catherine M. O'Hara, and Mitchell Troy of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1).

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EOS MLS Level 1B Data Processing Software, Version 3

This software is an improvement on Version 2, which was described in "EOS MLS Level 1B Data Processing, Version 2.2," *NASA Tech Briefs*, Vol. 33, No. 5 (May 2009), p. 34. It accepts the EOS MLS Level 0 science/engineering data, and the EOS Aura spacecraft ephemeris/attitude data, and produces calibrated instrument radiances and associated engineering and diagnostic data. This version makes the code more robust, improves calibration, provides more diagnostics outputs, defines the Galactic core more finely, and fixes the equator crossing.

The Level 1 processing software manages several different tasks. It qualifies each data quantity using instrument configuration and checksum data, as well as data transmission quality flags. Statistical tests are applied for data quality and reasonableness. The instrument engineering data (e.g., voltages, currents, temperatures, and encoder angles) is calibrated by the software, and the filter channel space reference measurements are interpolated onto the times of each limb measurement with the interpolates being differenced from the measurements. Filter channel calibration target measurements are interpolated onto the times of each limb measurement, and are used to compute radiometric gain. The total signal power is determined and analyzed by each digital autocorrelator spectrometer (DACS) during each data integration. The software converts each DACS data integration from an autocorrelation measurement in the time domain into a spectral measurement in the frequency domain, and estimates separately the spectrally, smoothly varying and spectrally averaged components of the limb port signal arising from antenna emission and scattering effects. Limb radiances are also calibrated.

The radiance at the limb port of the radiometer module is computed, including non-atmospheric radiance contributions from antenna emission and scattering. It is the task of the retrieval/forward model software (Level 2) to compute the atmospheric component of the limb radiation reaching this interface. It is necessitated by the greatly increased bandwidth of EOS MLS radiometers, and the

double-sideband nature of most measurements. Estimates of the random component of uncertainty (noise) on each limb radiance are also determined. Spacecraft inertial pointing and star tracker data are combined with spacecraft and GHz antenna structural/thermal data and scan mechanism encoder data to estimate the boresight angles for each radiometer. The software collects and generates ancillary data (e.g., tangent point location, local solar time, local solar zenith angle, flags for bright objects in the field of view) that are needed in Level 2 processing. A log file is produced that summarizes instrument performance and outputs.

This work was done by Vincent S. Perun, Robert F. Jarnot, Paul A. Wagner, Richard E. Cofield IV, and Honghanh T. Nguyen of Caltech and Christina Vuu of Raytheon for NASA's Jet Propulsion Laboratory. For more information, contact iaoffice@jpl.nasa.gov.

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⟩ Cassini Tour Atlas Automated Generation

During the Cassini spacecraft's cruise phase and nominal mission, the Cassini Science Planning Team developed and maintained an online database of geometric and timing information called the Cassini Tour Atlas. The Tour Atlas consisted of several hundreds of megabytes of EVENTS mission planning software outputs, tables, plots, and images used by mission scientists for observation planning. Each time the nominal

mission trajectory was altered or tweaked, a new Tour Atlas had to be regenerated manually.

In the early phases of Cassini's Equinox Mission planning, an *a priori* estimate suggested that mission tour designers would develop approximately 30 candidate tours within a short period of time. So that Cassini scientists could properly analyze the science opportunities in each candidate tour quickly and thoroughly so that the optimal series of orbits for science return could be selected, a separate Tour Atlas was required for each trajectory.

The task of manually generating the number of trajectory analyses in the allotted time would have been impossible, so the entire task was automated using code written in five different programming languages. This software automates the generation of the Cassini Tour Atlas database. It performs with one UNIX command what previously took a day or two of human labor.

This work was done by Kevin R. Grazier, Chris Roumeliotis, and Robert D. Lange of Caltech for NASA's Jet Propulsion Laboratory. For more information, contact iaoffice@jpl.nasa.gov.

This software is available for commercial licensing. Please contact Daniel Broderick of the California Institute of Technology at danielb@caltech.edu. Refer to NPO-47282.

⟩ Software Development Standard Processes (SDSP)

A JPL-created set of standard processes is to be used throughout the lifecycle of software development. These SDSPs cover a range of activities, from management and engineering activities,

to assurance and support activities. These processes must be applied to software tasks per a prescribed set of procedures. JPL's Software Quality Improvement Project is currently working at the behest of the JPL Software Process Owner to ensure that all applicable software tasks follow these procedures.

The SDSPs are captured as a set of 22 standards in JPL's software process domain. They were developed in-house at JPL by a number of Subject Matter Experts (SMEs) residing primarily within the Engineering and Science Directorate, but also from the Business Operations Directorate and Safety and Mission Success Directorate. These practices include not only currently performed best practices, but also JPL-desired future practices in key thrust areas like software architecting and software reuse analysis. Additionally, these SDSPs conform to many standards and requirements to which JPL projects are beholden.

This work was done by Milton L. Lavin, James J. Wang, Ronald Morillo, John T. Mayer, Barzia Jamshidian Tehrani, Kenneth J. Shimizu, Belinda M. Wilkinson, Jairus M. Hihn, Rosana B. Borgen, Kenneth N. Meyer, Kathleen A. Crean, George C. Rinker, Thomas P. Smith, Karen T. Lum, Robert A. Hanna, Daniel E. Erickson, Edward B. Gamble Jr., Scott C. Morgan, Michael G. Kelsay, Brian J. Newport, Scott A. Lewicki, Jeane G. Stipanuk, Tonja M. Cooper, and Leila Meshkat of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1).

This software is available for commercial licensing. Please contact Daniel Broderick of the California Institute of Technology at danielb@caltech.edu. Refer to NPO-47301.