Coordinating Multiple Spacecraft Assets for Joint Science Campaigns

Tara Estlin, Steve Chien, Rebecca Castano, Joshua Doubleday, Daniel Gaines, Robert C. Anderson, Benjamin Bornstein, Charles de Granville, Russell Knight, Gregg Rabideau, and Benyang Tang

Jet Propulsion Laboratory, California Institute of Technology
4800 Oak Grove Drive
Pasadena, CA 91109
{*firstname.lastname*}@jpl.nasa.gov

Planning, scheduling and execution techniques have been successfully applied on several NASA missions to coordinate onboard spacecraft behavior with little or no communication with ground (Chien, et al, 2005; Jonsson, et al., 2000). Further, technology to support the onboard handling of opportunistic science measurements is being applied on several spacecraft including the Mars Exploration Rover Mission (Castano, et al., 2007a; Estlin, et al., 2009). Based on the success of these applications, a new paradigm of space science campaigns is now being investigated where opportunistic science observations are autonomously coordinated between multiple spacecraft. This paper describes technology to support this new paradigm and specifically illustrates how science observations can be cross-cued between a surface asset, such as a rover or lander, and an orbiter.

In this paradigm, opportunistic science detections can be cued by either asset where the second asset is requested to take additional observations characterizing the identified surface feature or event. This type of coordination will enable a number of science campaigns not possible with present technology. Multiple spacecraft assets already exist for Mars and are planned for several other planetary bodies including Titan (where plans call for an orbiter, aerobot and potentially a surface rover or lander) and the moon (where plans currently include several orbiters as well as multiple surface vehicles). Some examples of applications for this paradigm on Mars include the orbital detection and in-situ characterization of ice geysers, trace gases, seismic events, and surface changes, such as new gullies and dark slope streaks (which are shown in Figure 1). These features are not fully understood by scientists and data taken close after their appearance is considered highly valuable. Extensive atmospheric campaigns can also be conducted to characterize dust devils, clouds and dust opacity using simultaneous orbiter and surface asset observations. Figure 2 shows a dust-devil captured by the MER rovers and dust-devil tracks captured by the Mars Odyssey orbiter. Simultaneous observations by multiple assets have been taken in flight; for example, Mars Global Surveyor TES (Thermal Emission Spectrometer) measurements and MER Mini-TES measurements have been coordinated in the past to take lower and upper atmospheric measurements at the same time. However, these measurements only occurred after labor-intensive manual coordination by the two operations teams. Coordinated asset campaigns are applicable to a number of platforms, including orbiters, landers, rovers, and aerobots.

Figure 1. Dark slope streaks on Mars. Image taken by Mars Orbital Camera (MOC) on Mars Global Surveyor (MGS).

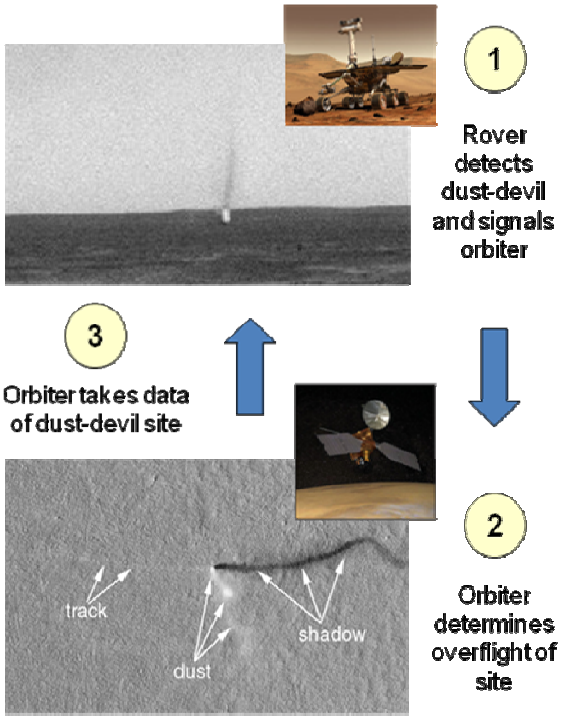

Figure 2. One scenario used in demonstration of multiple spacecraft science campaign. For this scenario, a rover detects a dust-devil on the surface and signals an orbiter to take an additional image of the area on its next overflight.

In this new application, technology from several project are being applied to provide science event detection and handling capabilities. Surface capabilities are currently being provided through the OASIS system (Castano, et al., 2007a) which includes surface asset identification of terrain features or events (e.g., detecting a dust-devil on the ground[1]) and handling characterizations of features identified by other assets (e.g., an orbiter sees a new surface feature that could be characterized by the rover). Orbital capabilities are provided through software developed for the Autonomous Sciencecraft Experiment (ASE) (Chien, et al, 2005) and Sensor web (Sherwood, et al., 2006) applications, which can identify planetary events from orbit and re-task an orbiter or satellite to take additional observations of key areas. Both of these systems use the CASPER planning system (Chien, et al., 2000) to handle online spacecraft command sequence modification in response to new science opportunities. During plan execution, CASPER monitors spacecraft states and resources and ensures new science activities are only added if enough time and other resources (such as power) are available. CASPER is also integrated with the Delay Tolerant Network (DTN) (Burleigh, et al., 2006), which is being developed to provide the next generation of spacecraft relay and networking services.

In November 2008, a multi-asset demonstration was performed in the JPL Mars Yard, which highlighted an atmosphere science campaign where a dynamic short-lived event, (e.g., dust-devil), is detected and characterized by two hardware platforms. To showcase the breadth of this type of campaign, two different scenarios were used. One part of the demonstration showed the detection of a dust-devil like motion by a rover, which then cued an orbital testbed (located also at the Mars Yard for this demonstration) to further characterize the dust-devil by taking additional observations of the dust-devil area on its next overpass. A second part of the demonstration showed the detection of dust-devil like motion by the orbital platform, which then cued a rover to temporarily suspend its current drive activities, point its mast camera at the location where the dust-devil was last observed, acquire an image of the location, and then resume its drive. This scenario highlights how landed assets could be cued or awoken when a surface event, such as a dust devil, is coming into range.

To display online results during the demonstration, a Google Earth application (shown in Figure 3) was devised that displayed science events as they are detected as well as spacecraft camera field-of-views and acquired imagery.

[1] Note, for identification of surface dust-devils, the MER rover dust-devil detected is used (Castatno, et al., 2005). To trigger a dust-devil detection in the JPL Mars Yard, a secondary robot was used to create motion in different areas of the yard which would trigger a detection.

References

Burleigh, S., Jennings, E., and Schoolcraft, J., "Autonomous Congestion Control in Delay-Tolerant Networks", *Proceedings of the Ninth International Conference on Space Operations*, 19-23 June 2006, Rome, Italy.

Castano, A., Fukunaga, A., Biesiadecki, J., Neakrase, L., Whelley, P., Greeley, R., Lemmon, M., Castano, R., Chien, S., "Automatic detection of dust devils and clouds at Mars," *Machine Vision and Applications*, 2007.

Castano, R., Estlin, T., Anderson, R. C., Gaines, D., Castano, A., Bornstein, B., Chouinard, C., and Judd, M, "OASIS: Onboard Autonomous Science Investigation System for Opportunistic Rover Science," *Journal of Field Robotics*, Vol 24, No. 5, May 2007.

Chien, S., Knight, R., Stechert, A., Sherwood, R., and Rabideau, G., "Using Iterative Repair to Improve Responsiveness of Planning and Scheduling," *Proceedings of the 5th International Conference on Artificial Intelligence Planning and Scheduling*, Breckenridge, CO, 2000.

Figure 3: Results of multiple spacecraft science campaign demonstration shown online in Google Earth application.

Chien, S., Sherwood, R., Tran, D., Cichy, B., Rabideau, G., Castano, R., Davies, A., Mandl, D., Frye, S., Trout, B., Shulman, S., and Boyer, D., "Autonomy Flight Software to Improve Science Return on Earth Observing One," *Journal of Aerospace Computing, Information, and Communication*, April 2005.

Jonsson, A., Morris, P., Muscettola, N., Rajan, K., and Smith, B., "Planning in Interplanetary Space: Theory and Practice," *Proceedings of the Fifth International Conference on Artificial Intelligence Planning Systems*, Breckenridge, CO, April 2000.

NASA Successfully Tests First Deep Space Internet, NASA press release 08-298, 18 November 2008.

Sherwood, R., Chien, S., Tran, D., Cichy, B., Castano, R., Davies, A., and Rabideau, G., "Autonomous Science Agents and Sensor Webs: EO-1 and Beyond," *Proceedings of the 2006 IEEE Aerospace Conference (IAC 2006)*, Big Sky, MT, March 2006.