

for surface, aerial, space, and water robotic vehicle visualization during field testing. It has been used to enable operations of wheeled and legged surface vehicles, and can be readily adapted to facilitate other mechanical mobility solutions.

The 3D visualization can render an articulated 3D model of a robotic platform for any environment. Given the model, the software receives real-time telemetry from the avionics system onboard the vehicle and animates the robot visualization to reflect the telemetered physical state. This is used to track the position and attitude in real time to monitor the progress of the vehicle as it traverses its environment. It is also used to monitor the state of any or all articulated elements of the vehicle, such as arms, legs, or control sur-

faces. The visualization can also render other sorts of telemetered states visually, such as stress or strains that are measured by the avionics. Such data can be used to color or annotate the virtual vehicle to indicate nominal or off-nominal states during operation.

The visualization is also able to render the simulated environment where the vehicle is operating. For surface and aerial vehicles, it can render the terrain under the vehicle as the avionics sends it location information (GPS, odometry, or star tracking), and locate the vehicle over or on the terrain correctly. For long traverses over terrain, the visualization can stream in terrain piecewise in order to maintain the current area of interest for the operator without incurring un-

reasonable resource constraints on the computing platform. The visualization software is designed to run on laptops that can operate in field-testing environments without Internet access, which is a frequently encountered situation when testing in remote locations that simulate planetary environments such as Mars and other planetary bodies.

*This work was done by Mark W. Powell, Recaredo J. Torres, David S. Mittman, James A. Kurien, and Lucy Abramyan of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1).*

*The software used in this innovation is available for commercial licensing. Please contact Daniel Broderick of the California Institute of Technology at [danielb@caltech.edu](mailto:danielb@caltech.edu). Refer to NPO-47945.*

## Athena

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The Athena simulation software supports an analyst from DoD or other federal agency in making stability and reconstruction projections for operational analyses in areas like Iraq or Afghanistan. It encompasses the use of all elements of national power: diplomatic, information, military, and economic (DIME), and anticipates their effects on political, military, economic, social, information, and infrastructure (PMESII) variables in real-world battle space environments. Athena is a stand-alone model that provides analysts with insights into the ef-

fectiveness of complex operations by anticipating second-, third-, and higher-order effects. For example, the first-order effect of executing a curfew may be to reduce insurgent activity, but it may also reduce consumer spending and keep workers home as second-order effects. Reduced spending and reduced labor may reduce the gross domestic product (GDP) as a third-order effect. Damage to the economy will have further consequences.

The Athena approach has also been considered for application in studies related to climate change and the smart

grid. It can be applied to any project where the impacts on the population and their perceptions are important, and where population perception is important to the success of the project.

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## In Situ Surface Characterization

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Operation of *in situ* space assets, such as rovers and landers, requires operators to acquire a thorough understanding of the environment surrounding the spacecraft. The following programs help with that understanding by providing higher-level information characterizing the surface, which is not immediately obvious by just looking at the XYZ terrain data.

This software suite covers three primary programs: marsuvw, marsrough, and marsslope, and two secondary programs, which together use XYZ data derived from *in situ* stereo imagery to

characterize the surface by determining surface normal, surface roughness, and various aspects of local slope, respectively.

These programs all use the Planetary Image Geometry (PIG) library to read mission-specific data files. The programs themselves are completely multimission; all mission dependencies are handled by PIG. The input data consists of images containing XYZ locations as derived by, e.g., marsxyz.

The marsuvw program determines surface normals from XYZ data by gathering

XYZ points from an area around each pixel and fitting a plane to those points. Outliers are rejected, and various consistency checks are applied. The result shows the orientation of the local surface at each point as a unit vector. The program can be run in two modes: standard, which is typically used for *in situ* arm work, and slope, which is typically used for rover mobility. The difference is primarily due to optimizations necessary for the larger patch sizes in the slope case.

The marsrough program determines surface roughness in a small area