Improved Path Planning Onboard the Mars Exploration Rovers

NASA's Jet Propulsion Laboratory, Pasadena, California

A revised version of the AutoNav (autonomous navigation with hazard avoidance) software running onboard each Mars Exploration Rover (MER) affords better obstacle avoidance than does the previous version. Both versions include GESTALT (Grid-based Estimation of Surface Traversability Applied to Local Terrain), a navigation program that generates local-terrain models from stereoscopic image pairs captured by onboard rover cameras; uses this information to evaluate candidate arcs that extend across the terrain from the current rover location; ranks the arcs with respect to hazard avoidance, minimization of steering time, and the direction towards the goal; and combines the rankings in a weighted vote to select an arc, along which the rover is then driven.

GESTALT works well in navigating around small isolated obstacles, but tends to fail when the goal is on the other side of a large obstacle or multiple closely spaced small obstacles. When that occurs, the goal seeking votes and hazard avoidance votes conflict severely. The hazard avoidance votes will not allow the rover to drive through the unsafe area, and the waypoint votes will not allow enough deviation from the straight-line path for the rover to get around the hazard. The rover becomes stuck and is unable to reach the goal.

The revised version of AutoNav utilizes a global path-planning program, Field D*, to evaluate the cost of traveling from the end of each GESTALT arc to the goal. In the voting process, Field D* arc votes supplant GESTALT goal-seeking arc votes. Hazard avoidance, steering bias, and Field D* votes are merged and the rover is driven a preset distance along the arc with the highest vote. Then new images are acquired and the process as described is repeated until the goal is reached. This new technology allows the rovers to autonomously navigate around much more complex obstacle arrangements than was previously possible. In addition, this improved autonomy enables longer traverses per Sol (a day on Mars), and can make planning drives easier for operators on Earth.

The Field D algorithm was developed and configured for MER by Anthony Stentz and David Ferguson of Carnegie Mellon University and integrated into MER flight software by Joseph Carsten and Arturo Rankin of Caltech for NASA's Jet Propulsion Laboratory.*

The software used in this innovation is available for commercial licensing. Please contact Karina Edmonds of the California Institute of Technology at (626) 395-2322. Refer to NPO-44504.

Robust, Flexible Motion Control for the Mars Explorer Rovers

NASA's Jet Propulsion Laboratory, Pasadena, California

The Mobility Flight Software, running on computers aboard the Mars Explorer Rover (MER) robotic vehicles Spirit and Opportunity, affords the robustness and flexibility of control to enable safe and effective operation of these vehicles in traversing natural terrain. It can make the vehicles perform specific maneuvers commanded from Earth, and/or can autonomously administer multiple aspects of mobility, including choice of motion, measurement of actual motion, and even selection of targets to be approached. Motion of a vehicle can be commanded by use of multiple layers of control, ranging from motor control at a low level, direct drive operations (e.g., motion along a circular arc, motion along a straight line, or turn in place) at an intermediate level to goal-position driving (that is, driving to a specified location) at a high level.

The software can also perform high-level assessment of terrain and selection of safe paths across the terrain: this involves processing of the digital equivalent of a local traversability map generated from images acquired by stereoscopic pairs of cameras aboard the vehicles. Other functions of the software include interacting with the rest of the MER flight software and performing safety checks.

This program was written by Mark Maimone and Jeffrey Biesiadecki of Caltech for NASA's Jet Propulsion Laboratory.

This software is available for commercial licensing. Please contact Karina Edmonds of the California Institute of Technology at (626) 395-2322. Refer to NPO-41261.

Solar Sail Spaceflight Simulation

NASA's Jet Propulsion Laboratory, Pasadena, California

The Solar Sail Spaceflight Simulation Software (S5) toolkit provides solar-sail designers with an integrated environment for designing optimal solar-sail trajectories, and then studying the attitude dynamics/control, navigation, and trajectory control/correction of sails during realistic mission simulations. Unique features include a high-fidelity solar radiation pressure model suitable for arbitrarily-shaped solar sails, a solar-sail trajectory optimizer, capability to develop solar-sail navigation filter simulations, solar-sail attitude control models, and solar-sail high-fidelity force models.

The integration of heliocentric or planetocentric trajectory design and optimization, with attitude control modeling, and navigation filter modeling, using a high-fidelity, arbitrary-shape sail model is new for solar-sail software. The present-day, state-of-the-art in solar-sail dynamics tools for analy-

sis are stand-alone tools for trajectory optimization, which generally use a very simple sail force model and stand-alone attitude control modeling. The current version, v2.1, is an update to a previous beta version.

This program was written by Michael Lisano, James Evans, and Jordan Ellis of Caltech; John Schimmels and Timothy Roberts of Raytheon ITSS; Leonel Rios-Reyes and Daniel Scheeres of the University of Michigan; Jeff Bladt of Ball Aerospace; Dale Lawrence of the University of Colorado; and Scott Piggott of Odyssey Aerospace Corp. for NASA's Jet Propulsion Laboratory.

This software is available for commercial licensing. Please contact Karina Edmonds of the California Institute of Technology at (626) 395-2322. Refer to NPO-43641.