DAYTIME COLOR IMAGE **MIDNIGHT INFRARED IMAGE**

A **Pothole Dug at a Construction Site** looks dark in a daytime image in visible light but looks bright in an infrared image acquired at midnight.

proximately inversely proportional to the square of the horizontal distance.

The method involves exploitation of the fact that throughout the night, negative obstacles are usually warmer than the surrounding terrain. Therefore, in infrared terrain images acquired at night, negative obstacles usually appear brighter than the surrounding terrain (see figure). (During the day, the negative obstacles can be warmer or cooler than their surroundings, depending on sky condi-

tions and the apparent position of the Sun.) At the present state of development, the method is embodied in a rudimentary algorithm that processes a combination of infrared imagery and range-versus-elevation data. The algorithm identifies candidate negative obstacles in the form of infrared bright spots on the terrain, then performs simple geometric tests to confirm or reject the candidate negative obstacles. The algorithm has been shown to be sufficient for initial proof-of-concept demonstrations. Further development of this or an improved algorithm will be necessary to enable reliable detection of negative obstacles under a variety of conditions.

Planning Flight Paths of Autonomous Aerobots

Trajectories are planned to satisfy survey coverage requirements without violating dynamical constraints.

NASA's Jet Propulsion Laboratory, Pasadena, California

Algorithms for planning flight paths of autonomous aerobots (robotic blimps) to be deployed in scientific exploration of remote planets are undergoing development. These algorithms are also adaptable to terrestrial applications involving robotic submarines as well as aerobots and other autonomous aircraft used to acquire scientific data or to perform surveying or monitoring functions.

These algorithms are built on a number of previously developed algorithms for planning optimal trajectories in two- and three-dimensional spaces. As used here, "optimal" could have any of a variety of different meanings. For example, "optimal" could be used to characterize a trajectory that passes through a set of waypoints specified by a user and that satisfies a minimum-length or a minimum-time criterion while also remaining within limits posed by dynamical and resource constraints. The present algorithms can also satisfy a requirement that the trajectory suffice to enable the field of view of camera aboard an aerobot to sweep all of a specified ground area to be surveyed (see figure).
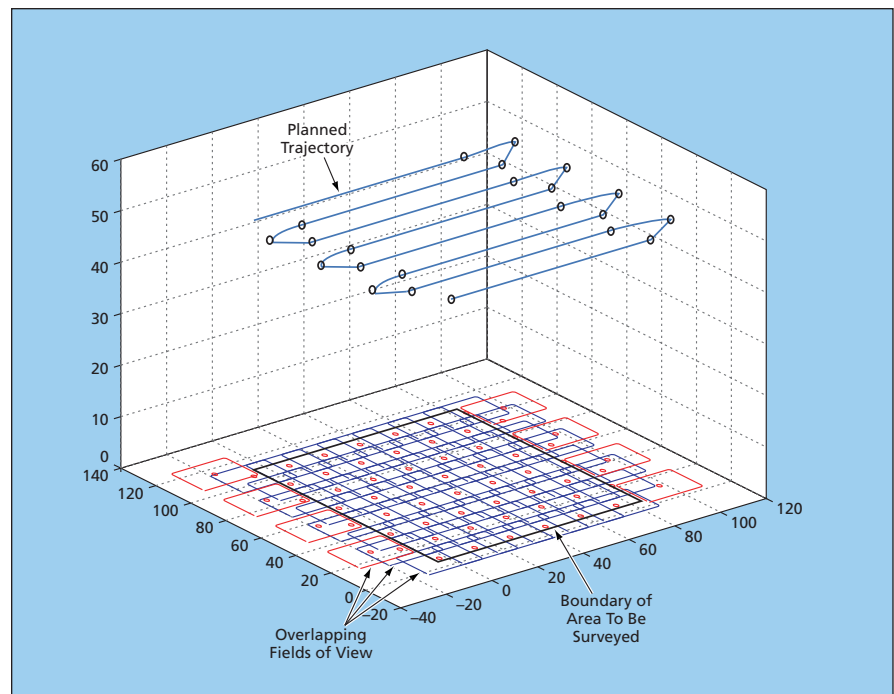
This **Raster-Scan Trajectory** was calculated to enable surveying, from a fixed altitude, of a defined rectangular area by use of a camera having a rectangular field of view. First, the survey area was mapped using successive fields of view that were required to overlap by 35 percent in length and/or width. Then the centers of the successive fields of view were designated as waypoints. Finally, the waypoints were used to generate the trajectory.

A navigation software system that implements these algorithms generates a simple graphical user interface, through which the user can specify either waypoints in two or three dimensions or the ground area to be surveyed. Alternatively, the user can load a data file containing waypoint coordinates. The user can also specify other parameters that affect the planned trajectory, including the field of view of the camera and the dynamical parameters, the primary one being the minimum allowable turn radius of the aero-

bot. Then assuming constant airspeed, the algorithms compute a minimum-time or minimum-length trajectory that takes account of all of the aforementioned requirements and constraints. Notably, in one of the algorithms, the turning dynamics of the aerobot are represented by a cubic spline that is used to interpolate the trajectory between waypoints.

In some contemplated future versions, the need for intervention by human users would be reduced: Waypoints specified by users could be sup-

planted by data generated by onboard artificial-intelligence image-data-processing systems programmed to strive to satisfy mission specifications.

✿ Cliffbot Maestro

NASA's Jet Propulsion Laboratory, Pasadena, California

Cliffbot Maestro (see figure) permits teleoperation of remote rovers for field testing in extreme environments. The application user interface provides two sets of tools for operations:

stereo image browsing and command generation.

The stereo image-browsing feature allows the operator to see images in either 2D or 3D views. This is useful in order to

develop a route for the rover to safely drive, as well as identify interesting objects for scientific exploration.

The command-generation tool is used to author a script (using either a drag & drop interface, or a textual command-line one) and send it to the rover. These scripts are not only for driving, but also for sample collection, reconnaissance, imaging, and science data acquisition.

The software runs on dedicated hardware that can withstand extremely cold temperatures. Its test bed is a Panasonic Toughbook (or equivalent) rugged laptop operating in the deep Arctic for extended periods. While the hardware doesn't have to be cutting-edge, it must withstand continued cold.

Cliffbot Maestro also provides engineering metrics about the state of the rover, in order to monitor its health, as well as the condition of the robotic arm. This allows for remote support while in the field.
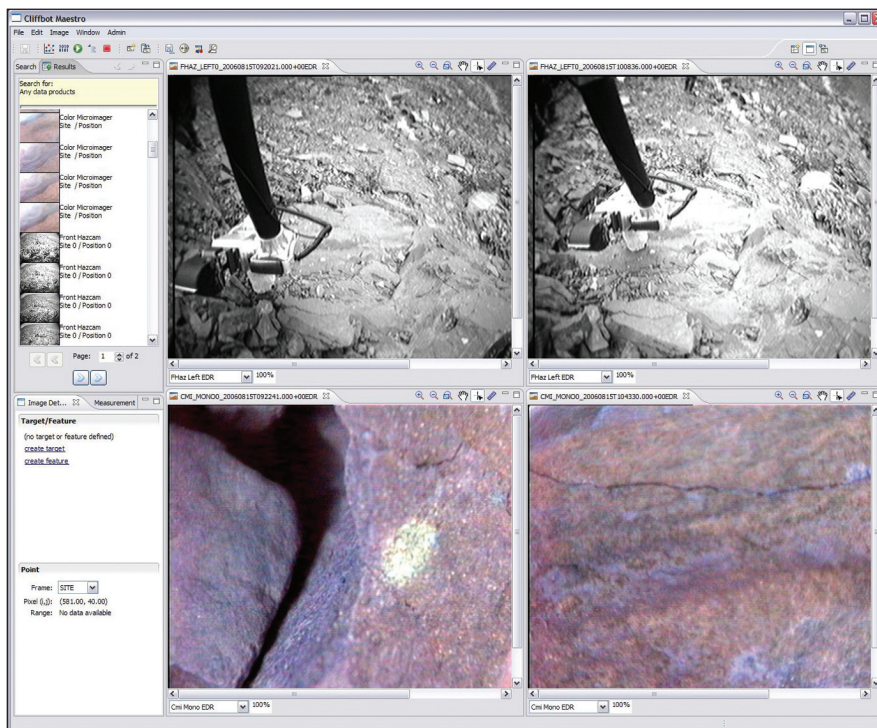
Cliffbot Maestro User Interfaces.

✿ Tracking Debris Shed by a Space-Shuttle Launch Vehicle

Lyndon B. Johnson Space Center, Houston, Texas

The DEBRIS software predicts the trajectories of debris particles shed by a space-shuttle launch vehicle during ascent, to aid in assessing potential harm to the space-shuttle orbiter and crew. The

user specifies the location of release and other initial conditions for a debris particle. DEBRIS tracks the particle within an overset grid system by means of a computational fluid dynamics (CFD) simulation

of the local flow field and a ballistic simulation that takes account of the mass of the particle and its aerodynamic properties in the flow field. The computed particle trajectory is stored in a file to be post-