The Imager for Mars Pathfinder (IMP) Experiment

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Abstract

IMP will land on the surface of Mars on July 4, 1997 and take the first pictures of the outflow delta of the Ares Valles river system. The imager is a multi-spectral, stereo camera with 12 filters per eye and a separation between the eyes of 15 cm. The imager rests on a pop-up mast 80 cm above the lander and 1.5 m above the surface and has full pointing ability. IMP will provide the mapping and orientation capabilities needed by the Pathfinder Rover, contouring the local topography. Several targets on the lander enhance the ability of the camera to study Mars: magnetic targets of varying strength will collect the magnetic component of the windblown dust, calibration targets allow spectra to be normalized for nearby rocks, and windsocks show the direction, speed, and vertical gradient of the local wind. Several science goals are being addressed with this experiment including the geology and weathering of the local terrain, the absorption properties of the atmosphere, the magnetic strength of the windblown dust, and the wind vectors.

Introduction

Pathfinder is the first of the new Discovery Missions announced by NASA and it adheres to the principles of "faster, better, and cheaper." JPL is building the spacecraft and has made a major effort to keep costs low because the program is threatened with cancellation if the cost-cap of $170M is exceeded.

Starting in July 1997, the Mars Pathfinder Mission will allow scientists a rare opportunity to study from close range the geology of the Ares Valles deltajust north of the martian equator (19.5°N, 32.8°W). The IMP team has designed, built, tested, and calibrated a multi-purpose camera (superior to the Viking lander cameras) that is cost capped at $6M and has been developed within a 1.5-year period. The camera has a resolution of 1 mrad/pixel and is fully pointable; software developed at LPL allows flexible commanding and includes 3 modes of data compression developed at the Technical University of Braunschweig under the direction of Dr. Fritz Gliem. A Loral CCD detector has been provided by Dr. H. Uwe Keller of the Max Planck Institute of Aeronomy and the camera has been designed and integrated by Lockheed Martin Astronautics of Denver.

Science Goals

The selected landing site is consists of a "grab bag" of rocks transported from the drainage basin of the Ares Valles. The goals of the IMP team are to

(1) Identify the physical processes that produced the morphology and small-scale structure of this previously unexplored area of Mars and relate it to the large-scale structures observed from orbit;
(2) Map compositional variations in the surroundings;
(3) Perform detailed analyses ofpristine lithologies and their weathered products;
(4) Measure the local winds and their vertical gradients;

and

(5) Identify the magnetic component of windborne dust.

Related goals designed to support or extend the capabilities of the Rover are:

(6) Produce a contour map of the local terrai n to aid the Rover in its traverses;
(7) Support Alpha, Proton, X-Ray Spectrometry (APXS) through a survey of the area accessible by the Rover and to document specific sample sites with spectral analyses prior to and subsequent to sampling; and
(8) Provide detailed spectral analyses of specific target regions outside the sampling radius of SAID to extend the interpretations of those results to the far field.

The first goal, to determine the geologic context of the landing site and the samples chosen for further analyses, is the exclusive responsibility of the imaging system. Immediately after landing, the first task will be to begin an imaging survey of the surrounding terrane. These data should be supported with stereo, multi-spectral imaging and close-up imaging of individual lithologies to allow team geologists to determine the fundamental processes dominating the site and thus guide the remainder of the mission strategy.

Camera Properties

IMP, designed to study the surface and atmosphere, is fully pointable from atop a popup mast and has stereo capability, 24 filters, and special targets. It also is used to track a small Rover. The resolution of the camera is 1.0 mead/pixel and it mosaics many small frames (256 × 256 pixels) to create a panoramic view. No mechanical shutter is necessary because of the frame transfer capability of the detector. The f/18 optics give a large depth of focus, low distortion, and freedom from aberrations; the exposure time can be commanded from 0.5 to 32,000 msec to properly expose each scene.

Stereo

The IMP is a stereo camera which creates image pairs in two ways. First, the camera is fully functional in its pre-deployment location at the top of the lander and will take a monochrome panorama soon after land- ing, these images will be compared to a similar panorama taken after the mast lofts the camera 80 cm above the lander surface for accurate ranging to distant objects. Second, the camera has two eyes horizontally separated by IS cm giving the normal stereo view. The ranging accuracy gives the location of a feature 2m from the camera to within ±5 mm, this error scales with the square of the distance to the object. Filter pairs in both the blue and red allow stereo views with different contrasts between surface features; Mars is known to have little contrast in blue light while having contrast variations on the order of a factor of two in the red.

Geologic Science

Each eye of the camera has a 12-position filter wheel spanning the allowable wavelength range of 0.4 to 1.05 µm. Experience gained by years of analyzing groundbased spectra have been distilled into the choice of 13 filters used to study the composition and weathering of the local terrain.

Studies of iron oxides are perfectly suited for IMP. For example, the shape of the spectrum in the 0.4 to 0.6 micron region can be used to infer both the stoichiometry of ferric oxide (Fe_2O_3) phases and their degree of crystallinity. The most diagnostic Fe_2O_3 feature is the strong hematite electronic band seen as a sharp change in the slope of the spectrum near 0.53 microns. Other crystalline forms of Fe_2O_3 have somewhat weaker bands located at slightly shorter wavelengths. To optimize the detection of these different features, bandpasses at 0.45, 0.48, 0.53, and 0.60 microns have been selected. These bandpasses are also similar to the centers of those on the Viking Orbiter, which will facilitate a comparison between IMP observations and the largerorbital database.

Atmospheric Science

Eight other filters are designed for studying the atmosphere by directly imaging the sun (the transmission of these filters are below 0.001); two are within the 935 nm water band and three are in neighboring continuum regions so that ratios between the band and continuum are sensitive to the atmospheric water vapor content at the level of a few pr µm. Other filters at 450 and 670 nm can be used to characterize the dust content of the atmosphere, imaging the sun at a variety of elevation angles and applying Beer's Law to f~nd the optical depth. Images of the sky at varying angles from the sun with the geology filters can contribute additional information about the scattering properties of the dust and its verti- cal distribution.

Magnetic Properties

The magnetic component of the wind-blown dust is studied by imaging the dust clinging to a series of magnetic targets of varying strength; these targets are provided by Dr. Jens Martin Knudsen of the University of Copenhagen. If the intrinsic magnetic strength of the dust is large all the targets will have a characteristic bullseye pattern on them, if weak, then only the stronger magnets will have material. Extensive calibrations have been done with a large sample of magnetic materials including iron oxides of various types and clays. In addition, the dust can be analyzed using a subset of the geologic filters to identify the spectral characteristics of the material.

Another magnetic target is located at the top of a mast longeron and can be viewed by a diopter lens in the filter wheel. The resolution is 150 µm/pixel and the alignment of the small grains along the field lines can be studied.

Wind Measurements

Three vertically displaced wind socks provided by Dr. Ronald Greeley of the Arizona State University are positioned on a 1 m tall mast located at the tip of a solar panel. They will be imaged at many times of the day to learn about the local wind velocity and its vertical gradient. The angle of the socks in response to differing wind velocities has been calibrated at Mars pressure in the Ames wind tunnel facility. Corrections for the lower gravity on Mars have been applied and tests indicate that the wind socks are sensitive to low speed winds from 5-50 m/s.

Calibration on Mars

Several calibration targets are needed to help interpret the camera performance and to estimate the diffuse flux of the sky. Two bulls-eye targets with 3 concentric circles of a known reflectance are positioned at differ- ent locations on the lander away from possible space- craft reflections. Each target has a blackened post in the middle that casts a shadow across the concentric rings of the target. Therefore, the target provides a known re- flectance for the sun plus sky illumination and also a shadow that is illuminated by the sky alone. The difference between the two gives the contribution of direct sunlight attenuated by the extinction optical depth of the atmosphere. By looking at the direct solar contribution at several wavelengths and times of day the spectral optical depth of the atmosphere can be reuieved.

Naturally, the CCD camera requires the subtraction of the dark count and the division of the flat field response. The dark current can be measured by pointing the camera straight down into its gimbal which is lined with special brushes that create a dark, dust-tight cavity. Flat field targets, calibrated at the Optical Sciences Center at the UA, are positioned at the top of the mast below the camera. Although these targets block some of the field of view of the lander, they do so in only one eye at a time.

Rover Tracking

One of the prime activities of the camera is to take a picture of the Rover at the end of each of its traverses. This is necessary to locate the exact position and orien- tation of the Rover so that the dead reckoning naviga- tion system can be reconnected to the local terrain map.

Data Compression Software

Data processing provides a broad range of capabilities, from full precision, 12-bit photometry to highly compressed (96:1) image transmission to less than 1 Kb data blocks for atmospheric extinction measurements. The principal method for compressing images consists of a requantization of the pixel data from 12 bits to 8 bits, followed by a least cosine transform (LCT) technique which permits additional target compression by factors ranging from 2:1 through 169.

These processes have been thoroughly studied for the IMP experiment.

The requantization is a square root-type process cutting off signal-dependent shot noise. At 100,000 electrons the noise is ±10 DN. Data numbers between 3090 and 4010 can be set to a single step with little loss. The algorithm preserves a signal-to-noise ratio of 100, wherever it exists in the original 12-bit data with minimal reduction in S/N for low signals.

The LCT is similar to the JPEG algorithm, but is more robust. Image data are divided into 8 × 8 pixel cells. The LCT is computed for each block, and the coefficients are sorted. Coefficients smaller than a threshold are eliminated and the remaining coefficients are requantized. The algorithm is global over the image, allocating more bits to blocks with more image activity. Output blocks are formed containing header information and coded coefficients.

LCT compression factors to 24:1 can be achieved for a full images, although degradation is seen at ratios above 12: 1. Instead, we achieve higher compression by subsampling the image (coadding pixels into 2 × 2, 3 × 3, or 4 × 4 blocks) or by limiting the rows and columns of data processed. IMP will also implement lossless compression for data requiring high precision. The current plan is to use the Y14 compressor developed by Rice and coworkers at JPL. This algorithm compresses images to near their differential entropy (usually by factors between 2: 1 and 3: 1) for 12-bit data.

Summary

The Pathfinder Mission is the first return to the surface of Mars since the Viking Landers in 1976. The Viking instruments returned evidence that no life exists today on Mars, but studies are showing that the ancient climate of Mars may have been very different. In particular, the pressure may have been high enough to support surface water and the associated lakebeds and hydro-thermal vents that are conducive to the formation of living organisms on the Earth. Pathfinder is ushering an age of exploration that will seek to unravel the secrets of this ancient Mars leading, in the next decade, to the return of rock samples for laboratory analysis.

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