Calibration of the Imager for Mars Pathfinder (IMP)

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Abstract

Calibration for true color is available through absolute spectroradiometric calibration at each of 17 different wavelengths. This allows the 12-bit data in each wavelength to be used in conjunction with a calibration of the display medium to present an approximation to the absolute spectral radiance of Mars.

Introduction

The Imager for Mars Pathfinder (IMP) is a stereo multispectral CCD camera scheduled to land on Mars July 4, 1997. More information on the IMP, and a sample color image which has been JPEG compressed, is available on the World Wide Web at:

http://www.lpl.arizona.edu/imp/imp.html

Calibration for true color is available through absolute spectroradiometric calibration at each of the 17 different wavelengths of the camera. This allows the 12-bit data in each wavelength to be used in conjunction with a calibration of the display medium chosen to present to the eye of the beholder an approximation to the true absolute spectral radiance of Mars. The accuracy of the overall color display system calibration is likely to be limited by the repeatability of the display medium. The IMP will be calibrated using NIST-traceable equipment calibrated within a 2.7% total absolute error budget. Spacecraft calibration targets will include both spectrally and spatially flat targets and color targets. The color targets will be characterized on earth, and will consist of minerals expected to be present on Mars which have been suspended in a silicone medium for adhesion to the spacecraft.

In order to produce the best data possible to support mineralogical, morphological, and atmospheric studies, the instrument must be both characterized and calibrated. The approach is to first characterize the instrument performance, then create a calibration data base which will allow optimal ground-based data reduction for scientific utility. We will also create on-board calibration which can provide the best possible compression of non-science data for use in support tasks such as rover navigation. On-board calibration and data compression will also provide a back-up mode of science data collection in the event that the high gain antenna is not available, forcing a very low data rate low gain antenna mission. In many cases, the raw instrument performance can be greatly improved by the use of tailored algorithms. One example is the use of a two-dimensional fit to the flat fielding variation as a function of wavelength to allow on-board calibration of field responsivity in each of the 24 spectral filters (17 different wavelengths) using a single flat field data table. Another example is the use of a centroiding algorithm to allow angular position and distance measurement limited by the signal-to-noise ratio, rather than limited by geometrical optics. The anticipated 0.06 pixel angular resolution requires careful calibration of optical train distortions due to many causes, including objective lens distortion and scale, and non-uniformities of detector response within a pixel. The ultimate goal is to attain the highest level of precision achievable with the Flight Model hardware in radiometric, spectroradiometric, and geometric data collection.

Instrument Characterization

Characterization is distinct from calibration, but is a necessary first step in the process. Among the characteristics of the IMP which must be measured are:

Depth of Focus (0.65 m to infinity)
Field of View
Stereo Alignment (30 milliradian toe-in per "eye")
Stereo Cross-Talk
Stereo Scale (matched to 0.1 %)
Stray Light
Geometric Distortions (create a stored correction map)
Modulation Transfer Functions (optical train quality)
- 8.1 On-Axis MTF for each Filter
- 8.2 Edge and Corner MTFs for each Filter
- 8.3 MTF as a function of Range (0.65 m to infinity)
- 8.4 MTF as a function of Pressure (earth ambient to Mars ambient)

Dark Current as a function of Temperature (165K to 280K)
Electron Well Depths (approx. 125,000 electrons)
Spectral System Quantum Efficiency as a Function of Pressure (to Mars ambient)
Alt.-Az Pointing Accuracy and Repeatability (accuracy of 5 mrad correctable to ?)
Charge Transfer Efficiency
Blooming
Responsivity Variation

15.1 Integrating Sphere Measurements
15.2 Target Measurements
15.3 Polarization Response
Optical Train Diffraction Effects (for each filter)

Calibration

The calibration data set is created from characterization data combined with absolute accuracy measurements. The calibration data will be used for all subsequent data reduction, and may be made available on CD-ROM when the Mars science data is released to the community at large. Three distinct calibration environments exist:
Laboratory Calibration
1.1 Radiometric Calibration
1.1.1 Responsivity as a function of Temperature
1.2 Spectroradiometric Calibration
1.2.1 Responsivity as a function of Wave length and Temperature
1.3 Flat Field Radiometric Calibration Data Sets
1.4 Geometric Calibration (includes AZ-EL)
Flight Calibration
Mars Site Calibration

Data Reduction

Several products of data reduction will be created for different science and engineering uses.
True Color
Panoramic Tiling
Multi-Spectral Classification
Three-Dimensional Classification Mapping of the Martian Surface
Atmospheric Studies
Solar Recognition

Engineering Model Performance

The IMP Engineering Model (EM) was at the University of Arizona from November 8, 1994 through January 16, 1995. During this brief period, a number of characterization tests were performed with three primary goals in mind:
Identify possible improvements to the IMP Flight Model
Verify and Validate the Flight Software
Obtain pointing accuracy and repeatability data for sun search

Several improvements to the Flight Model will be made as a result of these tests, and the data supports hope that the calibrated flight model will achieve several performance benchmarks of significance, including flat field response across the calibrated CCDs within 1% at all wavelengths. The IMP Science Team met during this period, and the IMP was exercised in the University of Arizona Mars Garden which contains earth analogs for some of the mineral and soil types expected to be found on Mars. This exercise highlighted the need for flat field accuracy, leading to improved flat field algorithms.

Flight Model Performance

As this is written, the Flight Model, which will travel to Mars, is undergoing testing in preparation for calibration. Further improvements in optical baffle alignment, focus, and pointing are expected prior to calibration. Vibration and shock testing to verify that the design will survive the voyage, including landing, has been performed. Thermal cryogenic high vacuum testing remains before calibration can begin. Initial characterization of the IMP has verified that optical distortion, modulation transfer function, and absolute sensitivity are within specifications.

Conclusions

The fast track schedule of a Discovery Mission means that the IMP Engineering Model was delivered within 6 months of contract award, and the Prototype Model will be delivered within one year of the initial contract, followed 3 months later by the Flight Model, which must be delivered to JPL after a scant 4.5 months of calibration. During that busy calibration effort, the data will be collected upon which the science from the first imaging mission to the surface of Mars in over 20 years will rest. A three-dimensional data set of the viewable Mars surface in each spectral filter will allow reconstruction of the absolute spectral radiance, and hence the true color, of the Martian surface.