A REVISED TARGET CALIBRATION PROCEDURE FOR IMAGER FOR MARS PATHFINDER AND SURFACE STEREO IMAGER FOR MARS POLAR LANDER DATASETS. R. J. Reid, P. H. Smith, M. T. Lemmon, and R. A Yingst, Lunar and Planetary Laboratory, The University of Arizona, P.O. Box 210092, Tucson, AZ 85721 (breid@lpl.arizona.edu).

Introduction: The Imager for Mars Pathfinder (IMP) returned over 16,000 high-quality images from the surface of Mars in 1997. The Surface Stereo Imager (SSI), a near duplicate of IMP on the Mars Polar Lander, will acquire images near the South Pole of Mars beginning December 3, 1999. Most scientific analyses of these datasets require some level of calibration, either into radiance units, or into units of reflectance.

The instrument calibration algorithm, called CCDCAL during the Mars Pathfinder mission (MPF), removed instrument-dependent sources of noise based on the laboratory calibration, such as flat field, dark current, bad pixels, and electronic shutter. This algorithm was improved to version 2, which includes correction to intensity units based on the absolute responsivity, better handling of pixel averaging, and the elimination of known bugs in the original version [1].

The target calibration algorithm, called SPECTCAL during MPF, uses measurements of radiometric targets (RT) to calibrate scene images to reflectance units. The RTs have a bull's eye design, with a inner white, middle gray, and outer black ring with a shadow post in the center. The original SPECTCAL was intended to provide a first-order calibration of scene images to reflectance units in order to facilitate spectrophotometric analysis. Since it was designed to be used during operations, several simplifications were required so that real-time analysis could be performed [1].

Now, in order to improve the rigorousness of the Pathfinder calibration, and to prepare for upcoming Mars Polar Lander operations, the target calibration procedure is undergoing significant revision.

The revision of the IMP/SSI target calibration procedure falls into three categories: 1) Elimination of software bugs in the original calibration; 2) Revision of correction algorithms used in the original calibration; 3) Addition of new algorithms to correct for sources of uncertainty that were ignored or unknown in the original calibration. The primary changes to the SPECTCAL v1 procedure are described below.

Bugs: Two significant bugs were discovered in the original CCDCAL algorithm. Since all images used for target calibration are first corrected for instrumental sources of noise, errors in CCDCAL affect the results of SPECTCAL. They have been corrected in v2 of the software.

Software Offset: The software offset was not removed from the raw image data. A bias of 16 data numbers (DN) was added to each image after readout to prevent underflow during processing. These 16 DN were not subtracted from any image processed with CCDCAL v1. This translated to a overestimation of radiance of about 0.5% for well exposed (~3000 DN) parts of the scene, with an increasing systematic overestimation as the total DN decreased.

Flat Field: The the flat fielding correction was applied incorrectly for subframes. Due to differences in correction array storage order from image array storage, flat fields were effectively applied upside down for subframes. Full-frame images were not affected. Since all RT images, as well as some important spectral datasets like the multispectral spots, were subframed, this can be a significant source of noise, as high as 3% band-to-band.

Improved Algorithms: Several algorithms from the first version of SPECTCAL have been reexamined and revised.

UA vs. DLR Target Measurements: Reflectance characteristics of the RTs were measured at both the University of Arizona (UA) and at the German Aerospace Research Establishment (DLR) in Berlin. The UA measurements were made at a single photometric geometry (i=0º, e=30º), and were used for SPECTCAL v1. The DLR measurements were made on witness samples of target material for a range of photometric geometries (i=0º to 50º, e=26º, az=0º to 180º), and did not become available until MPF operations had begun.

The absence of the DLR data in the original calibration caused errors in two ways. First, since the RTs are not quite Lambertian, different illumination geometries resulted in errors in calculating the reflectance of the targets. Second, since the IMP and SSI have stereo vision, each eye views the RT at different azimuths. This results in the RT having a different reflectivity of up to 5% between eyes, even when viewed at the same time. This effect caused significant errors between the two eyes and made construction of full spectra with visible (right eye) and IR (left eye) filters difficult.

Fitting Algorithm: A transfer function is created by fitting the measured target radiances to the laboratory-measured target reflectances. In the v1 algorithm, white, gray, and black rings were given equal weight. Several problems, including the software offset and specular brightening of the black target, resulted in these fits having a large bias term. Ideally, the fit should have no bias (since a surface with zero reflectance must have zero radiance). Therefore, the bias term was believed to be a result of scattered light within the camera, relevant only to the target environment, and was ignored. Later analysis demonstrated that scattered light was extremely small, and that the above factors were the primary cause of this effect.

The v2 transfer function forces the fit to go through the origin, and weighs the white and gray targets roughly equally, ignoring the black target, which has large systematic uncertainties. The new transfer function is derived from [3].

New Algorithms: There are several new algorithms that have been added to the target calibration procedure to account for factors that were either ignored or not understood at the time of landing.

Selection of Regions: Radiance measurements were made on the RTs by selecting regions from each target ring. During MPF operations, the procedure called for selecting the maximum number of pixels in each ring to minimize random errors. The random errors are small, however (<1%) compared to the variability of the radiance of the RT due to variations in sky illumination around the shadow post (~5%) [1].

In order to compensate for this, the new procedure calls for selection of identical regions of the RTs in both eyes. By limiting the regions of the RTs measured, better consistency is achieved both within each eye, and also eye to eye. This technique eliminates an average 1% error compared to the original technique.

Scaling of Brightness: Ideally, the observation of the RT occurred concurrently with the observation of the scene images that it was used to calibrate. In general, however, this was not the case, with the RTs being imaged hours or occasionally sols from the images that they were meant to calibrate.

With the development of an accurate atmosphere model [2], the total brightness can be determined at different times of day, permitting scaling of the RT measurements to have the effective values that they would have if imaged concurrently with scene images. This effect can have a large (~20%) effect on the determination of absolute reflectance of the surface, as well a smaller (~2%) effects on relative reflectance due to the variation in color of the sky illumination.

Dust on Targets: Dust accumulation at the MPF landing site has been measured to be ~0.25%/sol. Over the course of the mission, this translates to a ~22% change in dust coverage over the course of the mission. This change has been tracked in the measurements of the RTs by measuring the black/white radiance ratio over time. As dust accumulates, the black target (nominally ~4% reflective) brightens, and the white target (nominally ~96% reflective) darkens. The final version of this algorithm is still under development, and it will improve the calibration of images later in the mission when dust accumulation has become significant.

Additional Factors: There are additional factors influencing the calibration that are beyond the scope of the basic algorithm.

Direct/Diffuse Illumination Balance: The most significant additional factor that complicates calibration to absolute reflectance is the balance and spatial distribution of direct and diffuse illumination on both the surface and the RTs.

Laboratory reflectance measurements are general quantified in terms of bidirectional reflectance, that is, a single collimated beam illuminates the object, which is observed at a single emission angle. While the emission angle for IMP was fixed, the solar illumination geometry changes with each observation. Furthermore, due to a significant atmospheric opacity (~0.5), the amount of illumination from the sky was up to 50% of the total illumination of the surface.

While a first order separation of solar and atmospheric illumination can be performed on the RTs by measuring the radiance in both the shaded and sunlit portions of the target, they cannot be easily separated on martian surface materials without an understanding of the photometric and topographic properties of the surface.

The result of the target calibration has therefore been termed R*, defined as the total measured radiance of the surface divided by the total measured radiance of the RT scaled to its equivalent Lambert brightness [4]. This is conceptually similar to the radiance coefficient as defined by Hapke [5], but is not a true measurement of bidirectional reflectance, and should only be used with this caveat in mind.

Results: The v2 target calibration algorithm returns results that are generally similar to the results from SPECTCAL. The sum total of all of the improvements, however, does change the resulting reflectance spectra in both absolute and relative terms, and may lead to a reinterpretation of the spectral results.

One of the most significant results of the v1 algorithm was the absence of a band in the IR due to either ferrous or ferric mineralogy. Various explanations for this property of the spectra have been considered (cf. [6],[7]). The changes in the v2 algorithm (primarily the flat fielding error and revised transfer function) have changed the relative reflectance in a way such that a weak (~2-4%) absorption band is now observed in nearly all surface materials in the IR. While weak, this band shows variation in strength and central wavelength from material to material, and may be indicative of the ferric and ferrous mineralogy of the surface. [8],[9].

Since these new calibration results may require significant reanalysis and reinterpretation of the IMP dataset, the v2 target calibration algorithm is undergoing rigorous testing and comparison to the v1 SPECTCAL algorithm to ensure its validity. All current indications are that the v2 algorithms has significantly improved the accuracy of calibrating the IMP data to absolute reflectance, having a estimated band-to-band errors of ~2%.

References: [1] Reid, R. J., et al. (1999) JGR 104, 8907. [2] Tomasko, M. G., et al. (1999) JGR 104, 8987. [3] Reid, R. J. (1997) Master's Thesis, University of Arizona. [4] Bell, J. F. III, pers. comm. [5] Hapke, B. (1981) JGR 86, 3039-3054. [6] McSween, H. Y. Jr., et al. (1999) JGR 104, 8679 [7] Bell, J. F. III, unpublished manuscript. [8] Yingst, R. A. et al. (1999) LPSC 30th, 1912. [9] Yingst, R. A. et al., this volume.