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HiJACK: Correcting spacecraft jitter in HiRISE images of Mars

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Abstract

Since arriving at Mars orbit in March 2006, the High Resolution Imaging Science Experiment (HiRISE) onboard the Mars Reconnaissance Orbiter (MRO) has returned thousands of images of the surface of Mars at ~0.25 m/pixel ground sample distance [1]. The high resolution of HiRISE also makes it sensitive to geometric distortions due to spacecraft motion, which we call "jitter." We describe ongoing work involved in modelling the jitter motion in each observation and implementing a solution to update the camera pointing to produce images with minimal geometric distortions. This processing pipeline will be called HiRISE Jitter-Analyzed CK, or HiJACK. Jitter correction as shown here improves results from digital elevation modelling using HiRISE stereo pairs [2]. The HiRISE operations team plans to release precision geometric products to the Planetary Data System (PDS), including updated pointing kernels for use by the wider scientific community.

HiRISE Focal Plane Characteristics

HiRISE is a pushbroom camera, with 14 Charge-Coupled Devices (CCDs) arranged in a staggered array on a fixed focal plane (Fig. 1). Each CCD is 2048 pixels wide. The focal plane is covered by a three-band filter, collecting red visible wavelengths (RED) across the full width of an image, with two additional detectors in the visible blue-green (BG) and two in the near infrared (IR) in the center of the array. We take advantage of the cross-track overlap and the along-track time separation of the CCDs to gather information about the spacecraft motion [1].

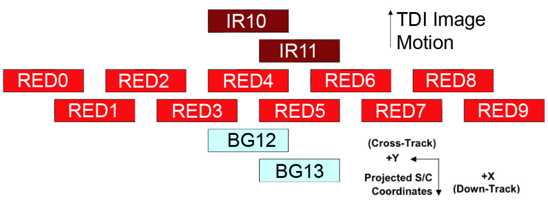

Figure 1: HiRISE focal plane layout (not to scale).

Resolving the Jitter

We begin with a set of CCDs that overlap a common CCD (e.g. RED3-4, RED4-5, BG12-RED4). Data from each CCD are radiometrically and geometrically calibrated [2, 3]. Any binned data are enlarged so the pixel dimensions from all CCDs are the same. We then measure the pixel coordinates of features in the overlap area of each CCD pair by using the ISIS 3 program *hijitreg* [4].

Relating the Offsets to Jitter

The key to reconstructing the jitter in a HiRISE observation is the fixed and known along-track separation of each CCD pair. If the ground coordinates of the features were known a priori, we could solve directly for the jitter displacement $j(t)$ between the expected and measured pixel coordinates of the feature at the time t of observation. Because the ground coordinates are not known, however, we can only measure the 'offset' $f(t)$ between the feature position in the second CCD of the pair and the location we would predict based on the first CCD and steady jitter-free motion. This is described by the equation

$$f(t) = j(t + \Delta t) - j(t) \qquad (1)$$

where Δt is the along-track time separation between the overlapping detectors.

We estimate jitter separately in the x and y directions. After filtering to remove outlier points, the offset data are spline-interpolated to a uniform time sampling. The uniformly sampled offsets are then transformed into the frequency domain by a fast Fourier transform (FFT). In this domain, the difference equation (1) corresponds to an explicit algebraic relation between the Fourier series coefficients for offsets and those for jitter. The jitter coefficients are solved for, results for the three CCD pairs are combined as described below, and a jitter time series is obtained by inverse FFT. As a check, offsets are computed from the reconstructed jitter series and compared to the observations. Average error is typically 0.1–0.3 pixel (Fig. 2).

Each CCD pair is effectively "blind" to jitter at frequencies with an integer number of cycles during the time offset Δt. HiRISE was designed to have different Δt for different CCD pairs, so that these blind spots fortunately do not overlap. Jitter coefficients at frequencies to which a given detector pair is blind are based on the average coefficients obtained from the other two pairs,

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whereas at other frequencies the coefficients from all three pairs are averaged.

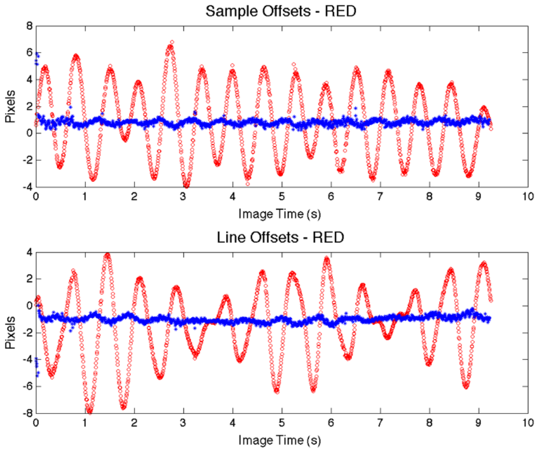

Figure 2: Results of jitter correction for HiRISE image PSP_008825_2040. Sample (x) and line (y) pixel offsets from the RED4-5 CCD pair are plotted before (red) jitter correction, and after (blue).

Applying the Correction

The x and y components of $j(t)$ describe the unwanted motion of features in the HiRISE focal plane. Producing a jitter-corrected image in which these unwanted displacements do not occur consists of three steps: interpreting $j(t)$ in terms of camera pointing angles, merging the new pointing data with the existing pointing information (in the form of a NAIF SPICE CK file [5]), and resampling the image.

Rotations of the spacecraft about the roll and pitch axes correspond directly to feature shifts in the x and y directions. The amount of rotation per pixel of displacement is given by the instantaneous field of view (IFOV), which is 1 µRad/pixel.

The "jitter angles" in roll and pitch are strictly relative to the nominal orientation of the camera. To merge these angles with the absolute pointing information in the SPICE CK, we factor the latter into a fixed rotation (the average orientation of the camera in inertial space during the image) and a time-varying relative rotation. The time-varying roll and pitch from the CK can then be replaced by the corresponding jitter angles (the third rotation angle, around the camera axis, is not constrained by the jitter model and is left unchanged). In practice, the jitter analysis described above does not recover the lowest frequency motions of the camera (average roll and pitch rates) so we estimate these rates separately, based on the average sample and line offsets $\langle j(t) \rangle$ over the whole image. The absolute orientation, average rates, and jitter angles are then recombined to yield an improved CK that describes the jittery pointing with which the image was actually obtained. An idealized, jitter-free CK is also created from the absolute pointing and average rates only.

If the CK including the jitter model is used to map project the image, jitter distortions will be accounted for and removed. To prepare the image for stereoanalysis [2], we use the ISIS 3 program *noproj*, which projects the image to the ground and then back up into an "ideal" version of the camera which has no optical distortion and no along-track offsets of its detector segments. If the jittery CK is used in the HiRISE-to-ground portion of this process and the jitter-free CK is used for the ideal camera portion, the resulting image will be jitter-free. Data from all ten RED CCDs can then be mosaicked in the ideal camera focal plane to yield a single large image with internal distortions limited to a fraction of a pixel.

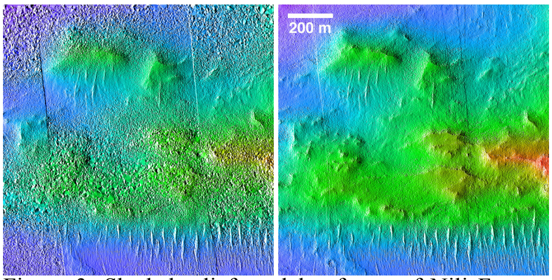

Figure 3: Shaded relief models of part of Nili Fossae, based on stereoanalysis of images before (left) and after (right) correction for jitter distortions. Rough texture at left is caused by jitter in y, which misaligns features for stereo matching. Lines running from upper left to lower right are caused by x-direction jitter, which changes discontinuously at the CCD boundaries. These jumps are reduced from >5 m to <0.5 m at right.

Conclusion

The algorithm described here successfully recovers the jitter function in a HiRISE image, which is then used to correct the pointing information, resulting in an image with almost no geometric distortions. The one condition that must be met to ensure success is the presence of a sufficient number of matchable features in the overlap between adjacent CCDs. This method has already been used to improve digital elevation model production (Fig. 3). Future plans include applying the method systematically to the complete set of HiRISE images and archiving high precision CK solutions for all images for which the analysis is successful.

References

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