Comparing Patch Orthorectification Algorithms in ISIS based on Camera Type. J. A. Anderson, U.S. Geological Survey, 2255 N. Gemini Drive, Flagstaff, Arizona 86001 (janderson@usgs.gov).

Introduction: The creation of accurately orthorectified planetary images (orthoimages) is critical for a wide variety of geospatial activities including cartography, change detection, landing site analysis, geologic mapping, rover traverse planning, and spectral analysis. Orthorectification, or projecting an image onto the 3-D shape of the target body, can be computationally time consuming [1]. Various patch orthorectification algorithms have been developed to improve the computational speed. We compare processing speeds using a reverse patch orthorectification algorithm and a hybrid forward-reverse patch orthorectification algorithm [2]. Three different types of instruments (a framing camera, a pushbroom camera, and a pushframe camera) will be tested with each algorithm.

Background: The USGS Integrated Software for Imagers and Spectrometers (ISIS) supports nearly fifty instruments from the older Apollo Metric, Viking, and Voyager cameras to the more modern instrument suites on Lunar and Mars Reconnaissance Orbiters. The support in ISIS for instruments includes rigorous physical camera models in conjunction with spacecraft orientation and positions (SPICE) from the JPL Navigation and Ancillary Information Facility (NAIF) [3, 4]. ISIS combined with SPICE provide the basis for examining the orthorectification speed variance between camera types for this study.

The process for creating an orthoimage (Figure 1) requires a camera model and map projection equation (e.g., Polar Stereographic). In the forward direction, the camera model is given an image coordinate (sample, line) from the raw observation (Figure 2) and the model computes a ground coordinate (latitude, longitude, radius) on a digital terrain model (DTM). The ground coordinate is then given to the map projection equation, which computes an orthoimage coordinate. The entire process can be reversed starting with an orthoimage coordinate and working backwards through the projection equation and camera model to compute a raw observation coordinate. Often, the backward process is preferred as it allows for pixel interpolation using bilinear or cubic convolution resampling.

The computational challenges in orthorectification can be seen by the need to apply the reverse projection equations and camera model at each orthoimage pixel coordinate. For instruments such as the High Resolution Imaging and Science Experiment (HiRISE), which collects 20,000 sample by 50,000 line observations, the orthorectification on a pixel-by-pixel basis would take nearly a day in ISIS.

Patch-based rubber sheeting algorithms have been available in ISIS and its precursors since the 1980s. The orthoimage is broken into NxN patches and the camera model and projection equations are used on the corners of the patch. Those four sets of input/output coordinates are used to compute affine transforms from orthoimage coordinates to raw observation coordinates. The speed of the algorithm increases as N grows because fewer camera model and projection computations are required; however, as N becomes too large, the error in pixel placement for the orthorectification can increase. Historically, ISIS has always used a reverse patch orthorectification process. In May 2012, a hybrid forward-reverse patch algorithm was added to ISIS.

In this algorithm, the raw observation image is broken into NxN patches and the forward camera model and projection equations are used to compute the output orthoimage coordinates given the four raw image coordinates. Affine transforms are still computed from orthoimage coordinates to raw observation coordinates; hence the hybrid forward-reverse patch algorithm still allows for bilinear or cubic convolution resampling.

In either algorithm, each patch is checked for its error. If the error is significant, the patch is broken into four equal-sized smaller patches, essentially a quad tree error handling mechanism, and new affine transforms are computed for each of the smaller patches. The sub-dividing process is repeated until the error condition is satisfied or until the patch size is two by two. The criteria for subdivision are applied when the coordinates at the center of the patch, using the affine transform, are in error by more than 0.1 pixels when compared to the coordinate computed using the camera model and map projection equations.

Analysis: A series of timed orthorectifications were run on the different camera types: the Dawn Framing Camera, Mars Global Surveyor (MGS) Wide Angle Camera (pushbroom), and Lunar Reconnaissance Orbiter (LRO) Wide Angle Camera (pushframe). For the framing camera and pushbroom cameras, five orthorectification tests were run 1) reverse pixel-by-pixel, 2) reverse patch with N=16 and N=4, and 3) hybrid forward-reverse patch with N=16 and N=4 (table 1). The predicted results were the hybrid algorithm would be faster than the reverse patch algorithm.

Table 1	Framing	Pushbroom
Image size (SxL)	1024 x 1024	640x768
Pixel-by-Pixel	32 sec	731 sec
Reverse N=4	18 sec	451 sec
Reverse N=16	10 sec	48 sec
Hybrid N=4	360 sec	24 sec
Hybrid N=16	468 sec	15 sec

At first glance, the time disparity between the two orthorectification algorithms was quite surprising. The Dawn framing camera image was an observation of the asteroid Vesta including the limb. The hybrid algorithm uses the forward camera model, which requireds an iterative technique for intersecting the DTM; this slows the orthorectification for framing cameras significantly. Conversely, the reverse algorithm for framing cameras is a direct computation in the camera model; hence the faster execution times.

For the MGS pushbroom camera, the forward algorithm must still intersect the DTM using an iterative algorithm; however, the reverse pushbroom camera model is iterative and much slower when determining the correct time (spacecraft position and orientation) a ground coordinate was observed.

The LRO WAC pushframe camera poses a different challenge. A pushframe operates much like a pushbroom but collects many lines instead of one. The LROC WAC collects fourteen lines and the patch size is therefore limited to that size or smaller.

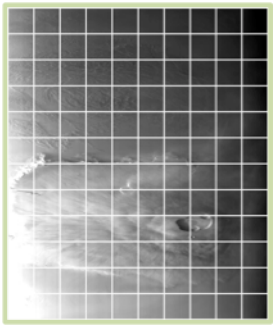
Table 2	Pushframe
Image size (SxL)	704 x 3640
Pixel-by-Pixel	705 sec
Reverse N=14	358 sec
Hybrid N=14	11 sec

For a pushframe camera, we again see the hybrid algorithm to be faster because the iterative method to determine the time a ground coordinate was observed is slower than the forward DTM intersection algorithm (table 2).

In all cases, a simple ratio between the truth image (i.e., reverse pixel-by-pixel) and the two patch orthorectifications using different patch sizes was computed. Visual analysis of the ratio image showed little or no difference between truth and patch algorithms when N=4 with the exception of the hybrid algorithm at the extreme limb of Vesta. There are apparent visual differences when N=16 for both algorithms.

Conclusions: Computationally, pushbroom and pushframe cameras are well suited to the hybrid orthorectification algorithm while the reverse orthorectification algorithm works better for framing cameras. Visually, smaller patch sizes produce better orthorectification, but results will need to be quantified in future analysis. The study of radar images and pushbroom observations of limb images is warranted, as well looking into improvements of the ISIS raster DTM intersection algorithm.

Finally, the analysis of pixel resolution of the DTM versus the observation image and how they impact patch size should be investigated. Course resolution DTMs, such as those created by the Mars Orbiter Laser Altimeter (MOLA), used in conjunction with HiRISE scale images may allow for larger patch sizes and hence faster run times.



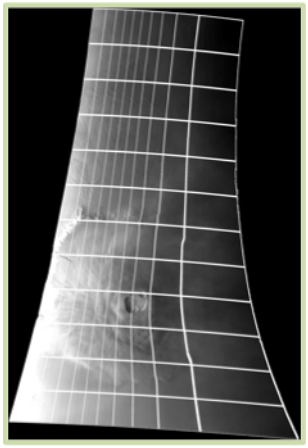


Figure 1 (right): Orthoimage
Figure 2 (above): Raw observation with grid lines representing 64x64 pixel patches used in hybrid algorithm

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