GEOLOGIC MEASUREMENTS USING ROVER IMAGES: LESSONS FROM PATHFINDER WITH APPLICATION TO MARS '01.

N.T. Bridges[1], A.F.C. Haldemann[1], and K.E. Herkenhoff [2]. [1]Jet Propulsion Laboratory, California Institute of Technology (MS-183-501, 4800 Oak Grove Drive, Pasadena, CA 91109; nathan.bridges@jpl.nasa.gov), [2]U.S. Geological Survey, Flagstaff, Arizona.

Introduction: The Pathfinder Sojourner rover successfully acquired images that provided important and exciting information on the geology of Mars. This included the documentation of rock textures, barchan dunes, soil crusts, wind tails, and ventifacts (1-5) (Figure 1). It is expected that the Marie Curie rover cameras will also successfully return important information on landing site geology. Critical to a proper analysis of these images will be a rigorous determination of rover location and orientation. Here, the methods that were used to compute rover position for Sojourner image analysis are reviewed. Based on this experience, specific recommendations are made that should improve this process on the ’01 mission.

Determining Rover Position and Orientation: Before effective quantitative analysis of rover images can be made, it is necessary to determine both rover position (x-y-z) and orientation (pitch-roll-yaw). For the Pathfinder mission, this was done using several methods. During a traverse, Sojourner estimated and recorded its own position and orientation by dead reckoning. However, these estimates often deviated from the true values due to uneven topography that affected the number of wheel turns per distance traveled, gyroscopic drift, and other factors. This frequently led to erroneous positions and orientations in the header information of rover images taken during mid-traverse. Without correcting this information, the computed locations of geologic features of interest (e.g., rocks, dunes) and their orientations (e.g., aeolian flutes, wind tails) were in error.

To reset Sojourner's knowledge of its own position and orientation, IMP (Imager for Mars Pathfinder) images taken at the end of each sol were analyzed. The images, compressed 6:1, generally consisted of 2 to 4 frame mosaics and as such occupied minimal downlink volume. This information was then used to update the rover on its proper location and attitude. However, this only proved effective for application to rover images that were taken at the beginning or end of a sol, when Sojourner was in the same position as that seen in the "end of day" IMP images.

To determine rover position in mid-traverse, when many of the best rover images were taken, three methods employing both IMP and rover images were used [3]: 1) Mid-traverse IMP stereo or monoscopic images of Sojourner at the time of rover imaging were used to compute the true rover position and orientation (“stereo” and “monoscopic” methods). These generally consisted of 24:1 compressed rover "movie" frames or images from panorama sequences that happened to image the rover. 2) Dead reckoning data in the rover image headers, dead reckoning data at the end of a traverse, and the IMP-derived true rover position at the beginning and end of a traverse were used to compute rover positions in mid traverse by estimating the drift in dead reckoning as a function of rover moves (“interpolation” method). 3) Where features visible in both rover and IMP images were known relative to IMP, the rover position was computed by tying the location of these image features together (“triangulation” method). Once the position of the rover was determined using these techniques, positions and orientations in the Mars surface fixed frame were computed (i.e., the frame used on Mars maps).

Error Analysis: When trying to determine the orientation of features in three-dimensional space using stereo rover images, the two main sources of error are the determination of orientation in the rover images themselves and the estimation of rover orientation. Knowledge of the latter is necessary to convert from the rover coordinate frame to the Mars surface fixed frame. Errors measuring positions in rover images affect both trend and plunge values, whereas uncertainties in the rover orientation mostly affect trends. In rover images, a line connecting endpoints of a given linear feature is made of N pixels and has N -1 pixel-pixel boundaries. The number of pixels depends upon both the length and the distance between the rover cameras and the feature. The number of orientations over which the pixels can be arrayed over a 180° range is $4(N\text{-}1)$. This gives a potential degree error within the image plane of $\pm 180°/(8[N\text{-}1])$. For the study of ventifacts described in [3]. values for this uncertainty varied from 0.4° to 4.4°.

In cases for which IMP stereo images documented rover position, rover orientation uncertainty was assumed to be a function of the pixel size of the rover in the images and was computed using the method described above (except in this case the number of pixels making up the rover length is substituted for the number of pixels making up the flute length). Where only monoscopic images were available, the error was judged to be twice as poor (i.e., $\pm 180°/(4[N\text{-}1])$). It was difficult to estimate the error using the interpolation method because the drift was in most cases probably not a linear function of the number of rover moves. Being conservative, the uncertainty was taken as the difference between the IMP-derived and dead reckoning position at the end of the traverse. The uncertainty using the triangulation method is also difficult to estimate but is probably of the order of 10°. Using all these methods, the error associated with rover position varied from 0.1° to 54° for the Pathfinder ventifact study [3]. The total uncertainty for this study, computed by summing the errors associated with positions in rover images and those associated with rover orientation, varied from 1 to 55°, but in most cases was less than 15°.

Recommendations for Mars '01: For the ’01 mission, it will be critical that the position of Marie Curie be known as accurately as possible when images are acquired. The following recommendations are offered to help achieve this:

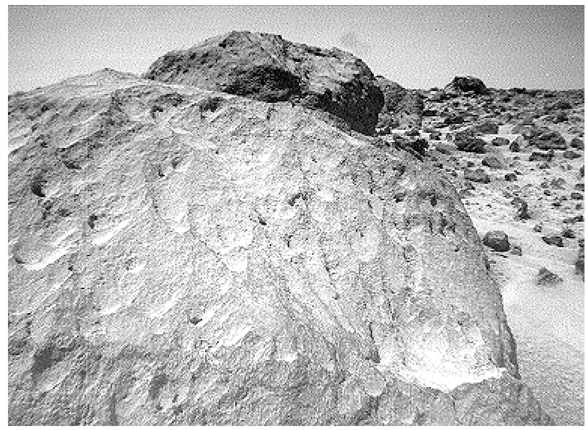
1) PANCAM images must be acquired at the end of each day during which a rover traverse takes place. These can be single filter, 6:1 compressed frames. When possible, similar PANCAM images should also be acquired in mid-traverse.

2) Pancam rover "movies" with 24:1 compression should be made when Marie Curie is traversing and imaging rough terrain.

3) Close-up stereo rover images should be nested within larger rover image mosaics such that surface features recognizable to both the rover and Pancam can be tied together. This will facilitate the computation of position in three-dimensional space

With these considerations in mind and taking into account the "lessons learned" from Pathfinder, the use of Marie Curie on Mars '01 should be very successful and teach us much about geologic processes on the Martian surface.

References: [1] Golombek M.P. et al., *J. Geophys. Res., 104*, 8523-8553, 1999. [2] Greeley, R. et al., *J. Geophys. Res., 104*, 8573-8584, 1999. [3] Bridges, N.T. et al., *J. Geophys. Res., 104*, 8595-8615, 1999. [4] McSween H.Y. et al., *J. Geophys. Res., 104*, 8679-8715, 1999. [5] Moore, H.J. et al., *J. Geophys. Res., 104*, 8729-8746, 1999.



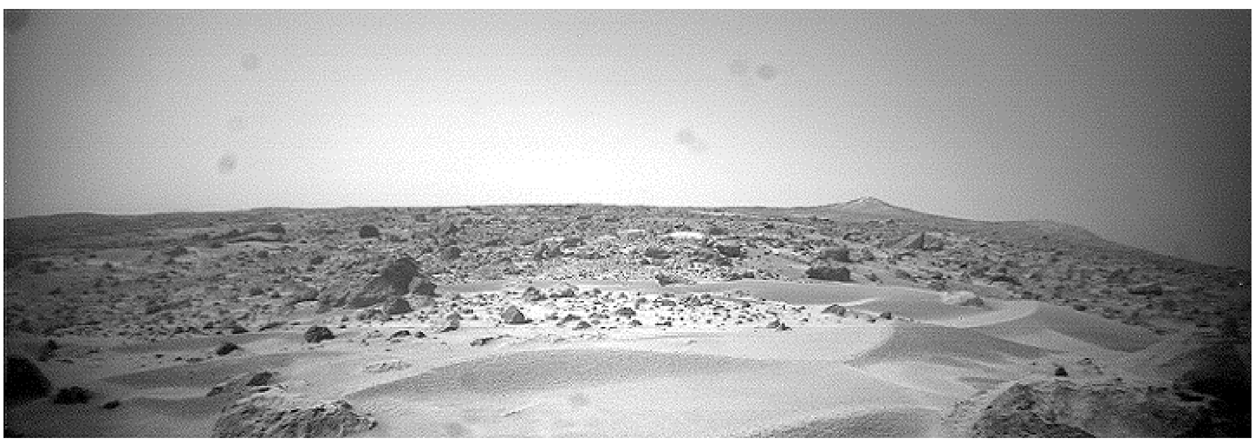


Figure 1: Examples of Pathfinder rover images that show geologic features for which deriving accurate position and orientation data is important. In the top frame, the rock Moe exhibits aeolian flutes. The bottom frame shows barchan dunes. Both features reveal important information about the present and past wind regimes that have operated at the Pathfinder landing site.