Correction of Image Motion Smear in Photo from Lunar Orbiter Mission I. Charles J. Byrne, Image Again, Middletown, New Jersey; cjbyrne@monmouth.com.

Introduction: The Lunar Orbiter camera compensated for image motion during an exposure by moving the platen that held the film. During the first Lunar Orbiter mission the image motion compensation device did not work properly, resulting in smear that made the high resolution images nearly useless. The second mission reexamined the potential Apollo landing sites, so no attempt was made to improve the smeared images. However, one early exposure of Mission I was of sufficient interest to be included in the book by Bowker and Hughes [1] and digitized by Jeff Gillis and the Lunar and Planetary Institute staff [2].

This exposure (subframes LO1-040-H1, H2, and H3) is of the eastern wall of the farside Korolev basin at 4.0 S, 157.4 W. The central subframe is shown in Figure 1. The author's destriping technique [3], [4] improves the quality of the images; however the image motion smear still makes the image difficult to interpret.

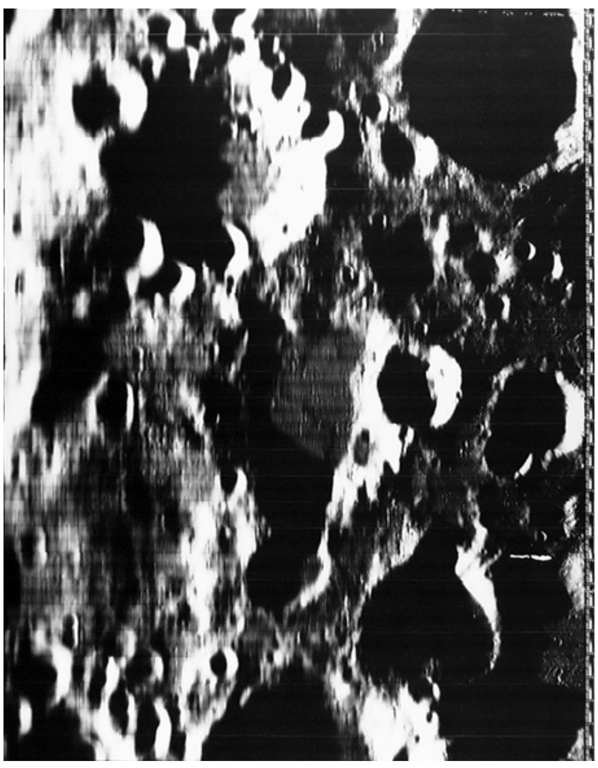

Figure 1: Subframe LO1-040H2 [2], showing the eastern edge of the Korolev basin. Note that the amount of uncompensated image motion varies across the subframe.

The smear is parallel to the length of the high-resolution exposure. The amount of the image motion varies across the subframe; At the edge near the calibration strip, there is no discernable image motion, while at the other edge, the motion is greater than that in the center. The camera had a moving-slit aperture [5]; apparently, the image motion was fully compensated at the start of the exposure, but degraded from the moment the exposure started to the time when it finished.

Smear Correction: The result of correcting the image motion smear is shown in Figure 2.

Figure 2: The subframe of Figure 1, processed to remove image motion. Note the increased sharpness, especially toward the left edge of the subrame, with better visiblity of small features such as the crater chains in the lower left.

Method of image motion correction: The type of restoration filter chosen to compensate for the effect of the smear is a Weiner filter [6]:

$$R(w) = \frac{D^*(w)}{|D(w)|^2 + \left(S(w)/N(w)\right)^{-1}}$$

where w is the spatial frequency in radians per pixel. Such a filter produces an image with a least-square error relative to an original image, given:

- The form of a distorting filter D(w); in this case, the image motion smear
- The spatial spectral density of the original image S(w) (inversely proportional to the square of the spatial frequency in this image of cratered terrain)
- The spectral density of additive noise N(w) (film granularity, quantization, and residual scanning artifacts)

The filter representing image motion smear of I pixels is:

$$D(w) = \frac{e}{jwI}\left(e^{jwI/2} - e^{-jwI/2}\right)$$

The parameters of the distorting filter, signal, and noise were estimated in order to determine the appropriate Weiner filter. The fourier transform of this filter was used as a convolution template for each vertical column of pixels (y dimension) in order to correct the image motion. Filter parameters such as the amount of the uncorrected image motion in pixels and the signal-to-noise ratio over the spatial spectrum were adjusted to obtain an improved image.

Variable Uncompensated Image Motion: Experimentation with several values of correction shows that the amount of uncompensated image motion varies across the horizontal (x dimension) of the image (Fig. 3). The motion rises approximately linearly from zero at the calibration strip toward the far edge.

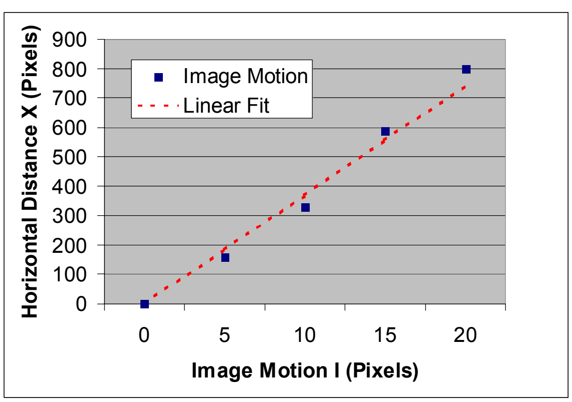

Figure 3: Horizontal distance X where correction of image motion I is optimal. The linear fit is X = 37* I.

Final Processing Technique: For each column of pixels, a Weiner filter was calculated for the amount of uncompensated motion appropriate to the distance of the column from the edge of the subframe. This filter (Figure 4) was transformed and used as a correlation template for the vertical y dimension (Fig. 5). Initial trials showed an undesirable enhancement of a harmonic of the framelet period, so the noise-to-signal ratio of the Weiner filter was increased at this frequency to compensate.

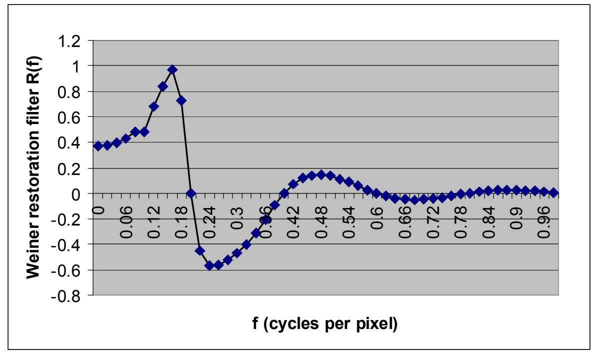

Figure 4: Example of a Weiner filter R(f) that corrects for an image motion of 10 pixels

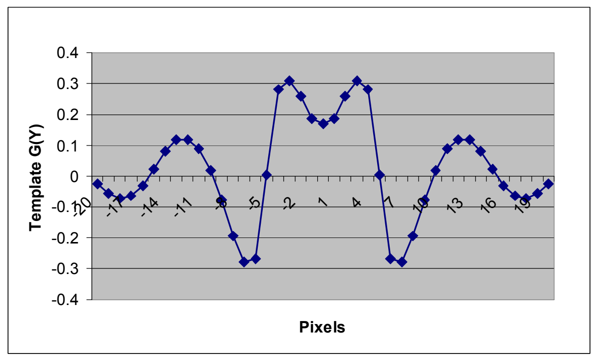

Figure 5: Example of a convolution template G(y) that corrects for an image motion of 10 pixels

References: [1] D. E. Bowker and J. K. Hughes (1971), *Lunar Orbiter Photographic Atlas of the Moon,* NASA SP 206. [2] J. Gillis (ed.), *Digital Lunar Orbiter Photographic Atlas of the Moon*, www.lpi.usra.edu/research/lunarorbiter, Lunar and Planetary Institute. [3] C. J. Byrne (2002), *Automated Cosmetic Improvement of Mosaics from the Lunar Orbiter Atlas,* LPS XXXIII, Abstract #1099, Lunar and Planetary Institute, Houston (CDROM). [4] C. J. Byrne (2002), *A New Moon: Improved Lunar Orbiter Mosaics,* The Moon Beyond 2002, Abstract #1128, Lunar and Planetary Institute, Houston (CDROM). [5] Boeing Aircraft, *Photo Subsystem Design and Calibration*, Lunar Orbiter Briefing Session V, c. 1964. [6] R. C. Gonzales and R. E. Woods, *Digital Image Processing,* Addison-Wesley Publishing Company, 2002.