REVIVING LUNAR ORBITER: SCANNING, ARCHIVING, AND CARTOGRAPHIC PROCESSING AT USGS.

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Introduction: We report on the status of a project to digitize, archive, and process a subset of the Lunar Orbiter (LO) photographic data. Following a successful pilot project [1, 2], our goal is to produce a global, cartographically accurate, cosmetically enhanced, digital photographic mosaic of the Moon using LO data. This mosaic will be coregistered to the Clementine 750-nm global mosaic [3].

Background: The full LO dataset consists of 967 medium-resolution (MR) and 983 high-resolution (HR) frames [4]. The LO images were photographic products acquired on the spacecraft in five missions (LO-I through -V) while in orbit over the lunar surface in the late 1960's. LO data were transmitted to Earth as analog data after onboard scanning of the original film into a series of strips. Photographic prints from these strips were hand-mosaicked into HR frames (3 sub-frames, or 96 strips per frame) and MR frames (~32 strips per single frame) and widely distributed. The resulting views were of generally very high spatial resolution and covered a substantial portion of the lunar surface. Obvious imperfections, such as "venetian blind" striping, variable density across strips, missing data, and saturation effects can be seen in many frames [5] and can inhibit their use. Scanning and manipulation of digital LO data can overcome some of these problems and produce unparalleled views of the lunar surface.

Film Handling and Digitization: An inventory of the LO film collections at USGS (Flagstaff, AZ) and the Lunar and Planetary Institute (Houston, TX) was completed in FY02. This required surveying ~3000 canisters at each location, identifying multiple copies of desired frames, and recording handwritten data on film-strip numbers, frames, resolution, "quality", and density for each canister. Film in each canister was then examined for completeness of strips, frame coverage (as compared to [2]), and validity of recorded film density for the type of terrain imaged. The best canisters were selected on the basis of contrast, coverage, and minimal artifacts. Data from a single canister are used where possible to maintain consistent density.

A CreoScitex Eversmart Pro II scanner, operated by proprietary software on a Mac platform, is being used to digitize the LO film strips. Film is cut, mounted on a template, and scanned 4 strips at a time. After thorough testing, these scanner parameters were applied: (1) An input film density (D) range of 3.0 to 0.6 preserves the dynamic range of the film and maps scanned data to an output DN range of 0 to 255; (2) The film is scanned at 25 microns and resampled to 50 microns for frame construction and further processing. One scanned strip makes a 16550x970 pixel image, with overlap between strips of ~37 pixels or less. At this resolution (a) fine geologic details observed on the film are retained in data resampled to 50 microns, and (b) differences in image quality between 8-, 25-, and 50-microns are largely due to film texture, random noise, and/or topographically modulated noise.

Quality control immediately follows scanning; each template is meticulously examined and rescanned if improvement is possible. The product is a TIFF image that preserves film data and can be ingested into ISIS readily. After validation in ISIS, digital files are converted to raw images and archived on DVD. As of December 2002, 112 frames (~10,752 strips) or ~80% of frames for global coverage have been scanned. About 10% of these data have been processed through frame construction and automated processing procedures are now in place.

Data Processing: Processing of the digital LO data (Figure 1) includes (1) *cosmetic processing* to suppress noise, resampling to 50 microns, and removal of dashed synchronization lines, (2) *geometric rectification and mosaicking* into subframes or frames, (3) *destriping* of the constructed frame, and (4) *cartographic control* via LO camera models for each mission and coregistration to the 750-nm Clementine tiles.

Cosmetic rectification. Clean-up of 25-micron film strips focuses on removal of noise and synchronization lines through the application of spatial filters. A low-pass-filter is applied to remove a random fine noise pattern and each strip is resampled to 50 microns. A tailored high-pass-filter models the dashed synchronization lines on the left and right edges of each strip and assigns them to nulls. Null pixels are filled in with averages of surrounding valid pixels.

Geometric rectification and mosaicking. Prior to the LO flights, the film was exposed with strip numbers, gray-scale bar, resolving power chart, and reseau marks. Each lunar film strip has 23 to 35 reseaux, and a single HR frame has ~2185 reseaux. Automated processing is used to locate and record the position of every visible reseau mark in each film strip, and these locations are mapped to their correct positions in the output frame via a "warp" process that uses a weighted least-squares fit to a 1st order polynomial describing the orthogonal positions of the reseaux. This mapping process also removes some film distortion. Reseau locations are a sparse control net and we are currently evaluating the quality and accuracy of constructed frames for future cartographic processing.

Destriping. Models of the striping patterns at several widths are created for each sub-frame mosaic by applying a series of low- and high-pass spatial filters. These models are then subtracted from the input sub-frame mosaic to remove stripes.

Cartographic control. (Figures 2A & 2B) Control of LO frame mosaics is accomplished through application of a camera model for each LO camera in ISIS. Development of the camera models required significant research on the LO photographic systems. Nominal values for positions of reseau and fiducial marks (286 sawtooth fiducials per HR frame, used as a cartographic frame of reference for each camera) were obtained from LO calibration reports [e.g., 5]. Required data for each full frame mosaic included these 10 values: misson number, frame number, date, time, and coefficients for spacecraft position and orientation. We received (and are hugely grateful for) considerable support from NAIF at JPL in identifying and refining these parameters. With these values, ISIS cartographic software can be applied to a constructed frame to project it to a given map projection and to calculate and report latitude, longitude, resolution, emission angle, incidence angle and phase angle for every pixel. Thus far, models for LO-IV and LO-V HR cameras are in place in ISIS, and a model for the HR LO-III camera will be completed soon. Models for the MR cameras for LO-IV, -V and -III are also planned for this year. LO-I data are not included because they do not include reseau marks. LO-II are not included because we cannot find the required documentation for this camera (possibly because the fiducial measurements for this camera were insufficient).

Summary and Future Work: Archived LO products to date include raw 25-micron digital film strips, mosaics for each frame and/or subframe (with and without cosmetic processing), and automated processing procedures for reseau location, frame construction, and cosmetic correction in ISIS. We are now well-positioned to establish geometric control of the LO mosaics through selection of tie-points between LO frames and Clementine 750-nm tiles, iterative triangulation, updating the LO spacecraft pointing information, rectification of the LO data to map projection, and creation of a global mosaic. An evaluation of optical distortions and possible modifications of LO camera parameters and/or pointing will also be conducted.

This project will result in digitization and processing of only a fraction of the LO data, and to date no "super-high-resolution" LO data have been scanned. We will request further comment from the user community to identify high-priority frames for possible future processing.

References: [1] Gaddis et al., 2001, Cartographic Processing of Digital Lunar Orbiter Data, in LPS XXXII, Abtract #1892. [2] See results and data from the Pilot Project at http://astrogeology.usgs.gov/Projects/LunarOrbiterDigitization/. [3] Eliason *et al.,* 1999, Mission to the Moon, The Clementine UVVIS Global Mosaic, PDS CL_4001-4078. [4] Bowker and Hughes, 1971, Lunar Orbiter Photographic Atlas of the Moon, NASA SP-206. [5] Gillis (ed.), 2000, Digital Lunar Orbiter Photographic Atlas of the Moon, LPI Cont. [6] Moyers, 1969, Improved Photo Support Data, Lunar Orbiter IV, NASA CR 66735-4.

Figure 1. Processing results for LO-IV frame 170H1.

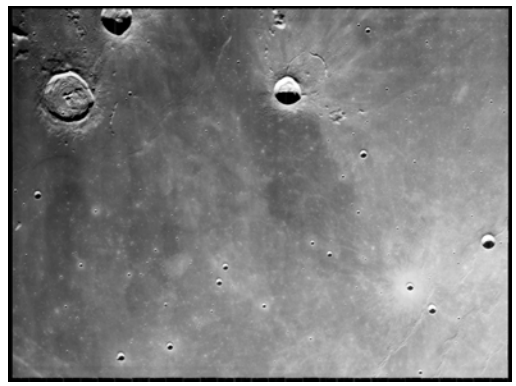

Figure 2(A). Reprojected LO-IV HR frames 091 and 103.

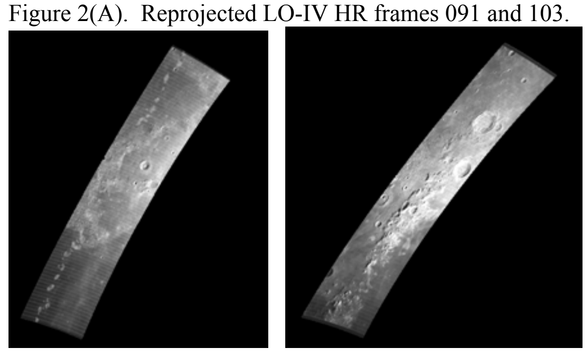

Figure 2(B). Footprints of LO-IV HR frames 091 and 103.