USGS LUNAR ORBITER DIGITIZATION PROJECT: UPDATES AND STATUS. L. Weller, T. Becker, B. Archinal, A. Bennett, D. Cook, L. Gaddis, D. Galuszka, R. Kirk, B. Redding, D. Soltesz, Astrogeology Team, U.S. Geological Survey, 2255 N. Gemini Drive, Flagstaff, AZ (lweller@usgs.gov).

Introduction: The Lunar Orbiter program of the mid-1960's successfully put five spacecraft into close orbits about the Moon. The thousands of photographs returned were used in support of future manned lunar landings (i.e., the Apollo program), and served as the basis of much scientific research. For more than three decades, lunar scientists have found great use in the generally high spatial resolution prints resulting from these missions [1, 2]. Over the past five years, the USGS Astrogeology Team has endeavored to bring a subset of these photographs, in a digital format, to the desktop of scientist and amateur alike through the Lunar Orbiter Digitization Project.

Project History: Upon completion of a pilot project during 2001 and 2002 [3], we started in earnest on the systematic undertaking of generating a Lunar Orbiter (LO) global mosaic of the Moon [4, 5]. This involved scanning over 30,000 LO filmstrips at 25-micron resolution, predominantly from LO-IV, and a small number from missions III and V for farside coverage. The scanning effort alone took nearly two years to complete. Once scanned and reviewed for quality, filmstrips were reassembled into the final photographic frame as viewed by the LO spacecraft. Nearly 200 reconstructed frames resulted from this effort. Ground resolutions range from 60 to 120 m for high-resolution (HR) frames (captured through the 610-mm lens) and 500 to 1000 m for the medium-resolution (MR) frames (captured with the 80-mm lens). The result of this initial effort will be a moderate resolution, near-global, cartographically controlled digital mosaic of the Moon.

In late 2003 and early 2004, as scanning for the global effort scaled back (with frame construction well in progress), another phase of the LO digitization effort began [6]. At low altitude, LO-III and -V collected hundreds of very high-resolution (VHR) frames of the lunar nearside equatorial region. Ground resolution of these data range from 1 to 5 meters for the HR frames and 10 to 40 m for the MR frames. Concurrent with the global venture, the VHR project [7] processed and delivered a portion of this very detailed imagery to the science community. To date, 166 frames (approximately 20% of the available data) have been scanned and assembled.

Constructed frames for both projects are available for download as 100-micron resolution TIFF images through the Lunar Orbiter Digitization web site (http://astrogeology.usgs.gov/Projects/LunarOrbiterDigitization/). As they become available, cartographically controlled and cosmetically enhanced data will also be distributed.

Data Processing: A majority of the work during 2006 focused on refining the camera models for LO-III, -IV and -V, and geometrically controlling the global and VHR frames. We briefly discuss these advancements below, but defer detailed analyses to future documentation through a USGS Open File Report.

HR Camera Distortion Modeling. Unlike the MR camera, LO mission documentation [8, 9] does not describe a distortion model for the HR cameras. A camera distortion effect in the LO-IV data was revealed during photogrammetric processing [10], encouraging development of a model to correct the behavior.

We modeled the optical distortion of LO-III, -IV and -V high-resolution cameras by measuring tiepoints between HR and simultaneously acquired MR frames. Feature coordinates in the MR frames were corrected for the known geometric distortion [8, 9]. In addition to determining (for the first time) the true focal length of each HR camera and measuring a radial distortion pattern, we found evidence of a "keystone" distortion in each camera. This results from a slight (<1°) misalignment of the fold mirror in the HR optics; we implemented the correction in our camera model as a simple transformation of the focal plane coordinates.

Boresight calculation. A fundamental component of all LO camera models is the calculation of boresight so that a true point of origin can be located for each frame. When available, fiducial marks are used to calculate the boresight. The quality and behavior of the fiducial measurements were examined while modeling the HR camera distortion. This revealed a common displacement between the outer two and center sub-frames of an HR frame. It was concluded that this resulted from slightly different boresights calculated from local sub-frame fiducial measurements. The LO HR frames are constructed in three separate sections or sub-frames consistent with their presentation in historic literature [e.g., 2]. Fiducial measurements and offset values for each sub-frame are now mapped into 'full-frame' space and used to calculate a single boresight for HR frames. This improved reconstruction of sub-frames into 'full frames' and generated a more accurate HR camera product.

Updates to MR camera boresight calculations were also conducted during this past year. Documentation of the LO MR camera [8, 9] is brief and subject to interpretation. More than one technique was tested to validate the MR camera boresight. While the details of this work are beyond the scope of this article, accurately calculating the HR camera boresight was integral to determining the boresight for the MR camera. A known offset exists between the HR and MR cameras for each mission [8, 9] and is utilized in determining the MR camera boresight. In the case of all LO frames, an accurate boresight value is not only important for geometric rectification, but is necessary in defining the point of symmetry for the documented and modeled radial distortion. These updates have been applied to all constructed frames prior to geometric control.

Geometric control. We are now focused on geometrically controlling the nearside frames of the LO-IV HR camera as part of the completion of the LO global mosaic. Techniques and methods developed from this work will be applied to the processing of the remaining farside data (LO-III and -V) as well as the VHR frames.

The nearside LO control point network consists of feature-referenced tiepoints measured in areas of overlap across adjacent LO-IV HR frames. In addition to this LO-to-LO network, we are continually adding a distributed number of measurements that tie to the Unified Lunar Control Network (ULCN) 2005 [11, 12]. The ULCN 2005 points supply the latitude, longitude and elevation coordinates which are held fixed as ground truth within the bundle-block adjustments. We are evaluating results of each iterative bundle-block adjustment based on these collected points and the improvements made to the LO camera models. If the results prove stable, we anticipate the integration of the LO-to-LO network into the ongoing refinement of the unified lunar control network.

Because LO data are being tied to the ULCN 2005, the LO network is in the Mean Earth/polar axis (ME) coordinate system. The orientation of the Moon at the epochs of the LO images has been obtained from the JPL DE403 ephemeris rotated to the ME system. The ME system has been used in the past for nearly all lunar cartographic products and continues to be recommended for such use [13, 14].

Global Project Update: Recent efforts on the global mosaic have concentrated on continued testing, validating and improving on characterizing the LO cameras. Use of LO data for the lunar farside add to the complexity of this work due to deep shadows (which lack discernible features to measure) and images containing limb and terminator. The integrity and positional accuracy of map-projected products is directly affected by the application of the HR camera distortion correction and accurate boresight calculations. We are now evaluating the results of iterative bundle-block adjustments using the collection of tiepoints to the ULCN 2005. Once a stable solution is reached, a final LO global mosaic will be constructed and made available.

VHR Update: Although no new frames were scanned this past year, considerable effort was put into cartographic control of data scanned and constructed over the past two years of the VHR project.

Very high resolution data have been geometrically controlled such that all overlapping frames falling within the same geographic location (or photographed site) coregister with one another. Tie points are currently being collected between these VHR data and the LO-IV global frames with which they overlap. The results of this will be VHR map-projected frames that coregister to the LO global mosaic and tie to the ULCN 2005.

Presently, we are reviewing film in preparation for scanning select data covering LO-V VHR sites V-48 (Aristarchus), V-43.2 (Gassendi), V-32 (Eratosthenes crater), V-35 (Copernicus secondaries), and V-15.1 (Dawes). Restraints on the number of frames we can scan preclude us from scanning all frames for these sites. Scanned frames will be shared with the community online as soon as they are constructed and validated.

Summary and Future Work: Future missions to the Moon have re-energized the lunar community and renewed interest in the Lunar Orbiter data. We are proud to offer these unique, and now digital, views of the Moon in support of current and future lunar science. We will continue to do so as long as the community and NASA support such an effort.

References: [1] Kosofsky and El-Baz (1970), NASA SP-200. [2] Bowker and Hughes (1971), NASA SP-206. [3] Gaddis et al. (2001), *LPS XXXII*, #1892. [4] Gaddis et al. (2003), *LPS XXXIV*, #1459. [5] Becker et al. (2004), *LPS XXXV*, #1791. [6] Becker et al. (2005), *LPS XXXVI*, #1836. [7] Weller, L. et al. (2006), *LPS XXXVII*, #2143. [8] USAF ACIC (1967), *Lunar Orbiter III Camera Calibration Report*. [9] USAF ACIC (1968), *Lunar Orbiters IV and V Camera Calibration Report*. [10] Rosiek et al. (2006), *International Archives of Photogrammetry, Remote Sensing, and Spatial Information Sci., XXXVI, Part 4*. [11] Archinal et al. (2006), *USGS Open File Report 2006-1367*. [12] Archinal, et al. (2007), *LPS XXXVIII*, #1904. [13] Davies, M.E., et al. (2000), *JGR, 105*, 20,277-20,280. [14] Seidelmann et al. (2005), *Cel. Mech. & Dyn. Ast, 91*, 203-215.