Lunar Cartography: Progress in the 2000's and Prospects for the 2010's

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The first decade of the 21st century has seen a new golden age of lunar exploration, with more missions than in any decade since the 1960's and many more nations participating than at any time in the past. In our previous papers (Kirk et al., 2006; 2007; 2008) we summarized the history of lunar mapping and reported on lunar mission planning for the 2000's. Here we report on the outcome of lunar missions of this decade, the data gathered, the cartographic work accomplished and what remains to be done, and an overview of what is known about mission plans for the coming decade.
Four missions of lunar orbital reconnaissance were launched and completed in the decade 2001–2010: SMART-1 (European Space Agency, 2003-2006), SELENE/Kaguya (Japan, 2007-2009), Chang'e-1 (China, 2007-2009), and Chandrayaan-1 (India, 2008-2009). In addition, the Lunar Reconnaissance Orbiter or LRO (USA, launched 2008) is in an extended mission, and Chang'e-2 (China, launched 2010) completed lunar operations in 2011. All these spacecraft have incorporated cameras capable of providing basic data for lunar mapping, and all but SMART-1 carried laser altimeters. Chang'e-1, Chang'e-2, Kaguya, and Chandrayaan-1 carried pushbroom stereo cameras intended for stereo mapping at scales of 120, 10, 10, and 5 m/pixel respectively, and LRO is obtaining global stereo imaging at 100 m/pixel with its Wide Angle Camera and hundreds of targeted stereo observations at 0.5 m/pixel with its Narrow Angle Camera. Chandrayaan-1 and LRO carried polarimetric synthetic aperture radars capable of 75 m/pixel and (LRO only) 7.5 m/pixel imaging even in shadowed areas, and most missions carried spectrometers and imaging spectrometers whose lower resolution data is urgently in need of coregistration with other data sets and correction for topographic and illumination effects. The volume of data obtained is staggering. As one example, the LRO laser altimeter LOLA has so far obtained approximately 5 billion elevation measurements, and the LROC cameras have returned 1,006,413 archived image products comprising over 250 Terabytes of image data.
The production of what could be considered controlled map products from these data is relatively limited as yet. The LOLA altimetry data have been subjected to a global crossover analysis, and local crossover analyses of Chang'e-1 LAM altimetry have also been performed. LRO Narrow Angle Camera stereo DTMs and orthomosaics of numerous sites of interest have been prepared based on control to LOLA data. Many useful data sets (e.g., DTMs from LRO Wide Angle Camera images and Kaguya Terrain Camera images) are currently uncontrolled.
Making controlled, orthorectified map products is obviously a high priority for lunar cartography. It should be clear, however, that scientific use of the vast multinational set of lunar data now available will be most productive if all observations can be integrated into a single reference frame. To achieve this goal, the key steps required are (a) joint registration and reconciliation of the laser altimeter data from multiple missions, in order to provide the best current reference frame for other products; (b) registration of image data sets (including spectral images and radar as well as monoscopic and stereo optical images) to one another and the topographic surface from altimetry by bundle adjustment; (c) derivation of higher density topographic models than the altimetry provides, based on the stereo images registered to the altimetric data; and (d) orthorectification, and mosaicking of the various data sets based on the dense and consistent

topographic model resulting from the previous steps. In the final step, the dense and consistent topographic data will be especially useful for correcting spectrophotometric observations to facilitate mapping of geologic and mineralogic features.

We emphasize that, desirable as short term progress may seem, making mosaics before controlling observations, and controlling observations before a multi-mission, multinational consensus on the best coordinate reference frame are counterproductive because they will result in a collection of map products that do not align with one another and thus will not be fully usable for correlative scientific studies.

Several lunar surface missions are projected for the decade 2011-2020, but these are customers for rather than producers of global and regional cartographic data. Such missions include Chandrayaan-2 (India/Russia), Chang’e-3 (China), SELENE-2 (Japan), and the private enterprises stimulated by the Lunar X-Prize. The US Lunar Precursor Robotic Program was discontinued in 2010, leaving NASA with no immediate plans for robotic or human exploration of the lunar surface. However, the GRAIL mission was launched in September 2011 and the orbital gravity measurements it will provide should facilitate future lunar navigation and illuminate the geophysics of the Moon’s interior. It may well be that the sequel to the decade of lunar missions 2001-2010 will be a decade of detailed and increasingly multinational analysis of lunar data from 2011 onward.

Kirk, R.L., et al., 2008, IAPRSSIS, XXXVII(4), 1473.
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