GEOMETRIC CALIBRATION OF THE CLEMENTINE UVVIS CAMERA. E. J. Speyerer¹, R. V. Wagner¹, and M. S. Robinson¹, ¹School of Earth and Space Exploration, Arizona State University, Tempe, AZ.

Introduction: The Clementine spacecraft launched in 1994 as part of a joint program between the Strategic Defense Initiative Organization and NASA [1]. During the mission, the Ultraviolet/Visible (UVVIS) camera [2,3] collected over half a million images of the lunar surface, which were later reduced into a detailed global multispectral mosaic and a series of mineralogy and maturity maps [4-8].

To facilitate the mapping exercises, efforts were made to geodetically control the images into a global control network. Specifically, in the late 1990’s, the United States Geologic Survey (USGS) and the RAND Corporation used over 500,000 match points to systematically control 43,871 images used in the 750 nm global basemap [3,4,9] to create the Clementine Lunar Control Network (CLCN). However, this analysis ignored topographic effects during the triangulation (i.e. assumed a spherical Moon with a radius of 1737.4 km) and later investigations showed the existence of large horizontal offsets (8-10 km) in the resulting maps due to extreme changes in the camera orientation parameters [10].

Later work improved upon this initial control network, with the creation of the Unified Lunar Control Network (ULCN) 2005 produced by the USGS [11]. While the ULCN 2005 included the local radius of the Moon during image triangulation, significant offsets (mean = 1.09 km; median = 1.59 km; Figure 1) still exist when compared to the current lunar reference frame. For this study, we use images acquired by the Lunar Reconnaissance Orbiter Camera (LROC) to update the Clementine UVVIS internal and external orientation parameters in order to create precise and accurate map products.

Clementine UVVIS Camera: The Clementine UVVIS camera was a framing camera capable of acquiring images in five different narrow bandpasses (415, 750, 900, 950, and 1000 nm) as well as a single broadband filter (400-1000 nm) using a filter wheel. The 5.6° × 4.2° field of view and 384 × 288 pixel CCD enabled the UVVIS camera to acquire images with a ground sampling distance of 115 m from an altitude of 425 km (although the point spread function of the optics reduces the true resolution).

LROC Wide Angle Camera (WAC): The LROC WAC is a push frame camera capable of providing images in seven different color bands (321, 360, 415, 566, 604, 643, and 689 nm) [12]. The WAC has a 90° field of view in monochrome mode and a 60° field of view in multispectral mode. From an altitude of 50 km, the WAC acquires images with a nadir pixel scale of 75 meters for the visible filters (384 meters for the UV filters). The WAC images almost the entire Moon each month, capturing the lunar surface under a variety of lighting conditions over time. Using the latest LRO ephemeris provided by the Lunar Orbiter Laser Altimeter (LOLA) and Gravity Recovery and Interior Laboratory (GRAIL) teams and the refined LROC camera model parameters, WAC images have a geometric accuracy of better than 45 m [13].

Controlling UVVIS and WAC Images: In order to improve the observational geometry of each Clementine UVVIS image, we first identified LROC WAC images acquired under similar lighting conditions (i.e. difference in sub-solar point between observations < 5°) that cover the UVVIS field of view. In many cases, a single Clementine image may match multiple WAC observations due to significant overlap at higher latitudes and the extensive WAC temporal coverage.

After calibrating and applying a photometric correction to the image pair, each WAC image is map projected to the surface using a global DTM (GLD100) [14]. These procedures are carried out using Integrated Software for Imagers and Spectrometers (ISIS) [15], which is developed and maintained by the USGS. The odd and even WAC framelets are mosaicked into a single mapped image. The mapped WAC image is then transformed back into the UVVIS camera space using an ISIS utility called map2cam. This enables each feature in the UVVIS image to be tied to a unique line and sample in the WAC observation.

The UVVIS/WAC image pairs are then registered using a series of control points. These control points are automatically derived using an ISIS utility called findfeatures that applies feature-based matching algorithms to detect similar features in each image. The software takes advantage of the OpenCV framework, which allows the user to select from a broad range of features, extractors, and matchers [16].

Geometric Calibration of the UVVIS Camera: The interior and exterior orientation parameters used by ISIS and NASA’s Navigation and Ancillary Information Facility (NAIF) are stored in a series of SPICE kernels. As part of this investigation, we are updating the interior and exterior orientation parameters archived in the Clementine UVVIS Instrument Kernel (IK), the C-Matrix Kernel (CK) and the Frames Kernel (FK). In addition we will be assessing the quality of a series of ephemeris kernels (SPKs).

Interior Orientation: From the output of findfeatures, we have collected thousands of UVVIS line and sample coordinates tied to points on the lunar surface (latitude, longitude, and radius) using coordinates of the corresponding feature identified in the WAC im-
Using procedures developed for in-flight calibration of the LROC WAC [13], we are able to derive a precise focal length, optical boresight (line and sample), and optical distortion of the camera. Preliminary results indicate that the effective focal length for the 415 nm UVVIS band is 0.15% less than the longest band (1000 nm). This difference is likely due to lateral chromatic aberration that is not captured in the current UVVIS camera model. This 0.15% difference in the focal length introduces a ~0.7 pixel error corner-to-corner when comparing images of same area with the two bands. By updating the interior orientation parameters stored in the IK, these distortions and offsets can be accounted for and removed during map projection.

**Exterior Orientation.** The exterior orientation parameters are stored in the C-Matrix Kernel (CK), Spacecraft Position or Ephemeris Kernel (SPK), and a Frames Kernel (FK). The CK stores the relative orientation of the spacecraft with respect to a base reference frame such as J2000. The FK contains the fixed angular offset of the UVVIS camera with respect to the spacecraft. This information along with the spacecraft position or ephemeris data stored in the SPK can be used to fully describe the location and orientation of the camera.

To adjust for offsets in the placement of UVVIS images on the lunar surface, the orientation (CK and FK) and/or spacecraft location (SPK) can be corrected. An adjustment to the spacecraft location or orientation will cause the image to shift along the surface when projected (Fig. 1). Adjusting the CK can introduce a small distortion that causes pixels on one side of the frame to be translated further than pixels on the opposite side (Fig. 1b). However, these effects are small given the offset observed in UVVIS images and the altitude at which the images were acquired (Fig. 1c). Therefore, we are keeping the SPK fixed and only adjusting the orientation of the UVVIS camera. Any systematic offsets will be compensated for with a fixed change in the FK while the remaining offsets will be accounted for in the CK that store orientation information for each UVVIS observation.

With this study, we are evaluating the quality of the three independently derived ephemeris solutions to describe the position of the spacecraft (Goddard Space Flight Center’s solution derived in 1994, Naval Research Laboratory’s solution from 1994 and Jet Propulsion Laboratory’s solution from 2007). Each SPK is evaluated based on the adjustments applied to the original CK derived by ACT Corp. to align the UVVIS image with the LROC basemap. The SPK with the least required adjustments to the pointing will be used as the base SPK for the remainder of the study and the orientation for each image will be derived from those stored position.

**Future SPICE updates:** Once the interior orientation parameters are refined for each UVVIS band and exterior orientation parameters are refined for each image, a new IK, FK, and CK will be generated and released via NAIF and included in an upcoming ISIS distribution. With these new kernels, images can be map projected with sub-pixel accuracy to the geodetic grid defined by the LRO mission, thus enabling quick future cross-mission analysis without the need to manually align the datasets.


**Fig. 1-** Image distortion due to SPK vs. CK adjustments. The difference (b-a) normalized to the altitude dependent ground sampling distance (GSD) of the UVVIS camera indicates that adjusting just one of the parameters will result in a precise solution (error < 0.01 pixel for typical orientation adjustments).