CONNECTING THE DOTS: PREPROCESSING APOLLO 15 PANORAMIC CAMERA IMAGES FOR PHOTOGRAMMETRIC CONTROL. Kenneth L. Edmundson1, B.A. Archinal3, T.L. Becker1, J.A. Mapel1, M.S. Robinson2, and M.R. Shepherd1, 1Astrogeology Science Center, United States Geological Survey, Flagstaff, AZ, USA, 86001 (kedmundson@usgs.gov), 2Arizona State University, Tempe, AZ, USA, 85287

Figure 1: Apollo 15 PC image AS15-P-0000 centered at ~19°.3S, 90°.7E (over Schorr crater). Scanned Tile 1 of 8 in red.

Introduction: A single film image (Figure 1) taken by the Panoramic Cameras (PC) flown on Apollo missions 15, 16, and 17 is 45 inches wide across-track by 5 inches along-track (1.1 m x 127 mm) [1]. For the casual observer, it can be difficult to see beyond the beautiful, high resolution lunar data that dominates the film, stretching ~210 miles (340 km) across the surface of the Moon. But looking closer, in the black borders of the film above and below the image data, are rows of little white dots. And they are the key to the photogrammetric control of the PC images.

Digital scans of the original PC negatives produced at film-grain resolution by the NASA Johnson Space Center and the Arizona State University (ASU) are available at the ASU Apollo Digital Image Archive (http://apollo.sese.asu.edu) [2]. Due to the large scanned file size (~16 Gb), each scan was made and is stored as 8 separate, overlapping 2 Gb image tiles (Figure 1). The U.S. Geological Survey Astrogeology Science Center (ASC) is utilizing this resource and their Integrated Software for Imagers and Spectrometers (ISIS) planetary cartography package [3] to control the ~1500 Apollo 15 PC images [4]. Below we describe PC image structure, camera operation, and the processing of each scanned tile from original TIFF to ISIS 3 cube format. Processing consists primarily of finding, interpreting, and recording those little white dots.

Image Structure: The dots are in fact scan angle fiducial marks and timing marks (Figure 2). A row of fiducials appears above and below the image data and define the image coordinate system.

A row of timing marks is beneath the bottom row of fiducials. This is a sequence of dots and dashes of varying length, in a modified IRIG-B time code format [5]. The code records at every full second, the complete time after launch in seconds, minutes, hours, and days. Between full seconds, marks are at 10 millisecond increments. It is the dynamic nature of the PC (Figure 3) that necessitated use of the timing marks.

PC Operation: During acquisition, the optical system rotated clockwise about an axis parallel to the flight direction while the film moved through the camera in the opposite direction. The film was exposed through a variable width slit that, similar to a pushbroom camera, defines the instantaneous focal plane. The horizontal image coordinate determines the time of exposure, used to compute camera position and pointing at that time. Image motion compensation (IMC) to minimize blur from the camera’s forward motion was implemented by tilting the entire assembly continuously backward during exposure.

The V/h (velocity/altitude) sensor, which determined the rate of apparent motion of the ground scene, regulated camera cycling rate, exposure, and IMC [7]. These values were in general variable and subject to error. On Apollo 15 this was aggravated by a drifting V/h sensor that would reset after wandering out of its normal operating range [8]. In some images this is clearly indicated by sudden changes in exposure and in the length of fiducial and timing marks. Exposing the timing marks directly on the image provided a more precise estimate of time [9].

Figure 2: PC film format (from [6], Fig. 4-3).

Figure 3: PC roll frame assembly (top) and stereo gimbal (bottom) (NASA).
Finding and Identifying the Dots: Fiducial and timing marks are automatically detected in all 8 image tiles with the help of the OpenCV computer vision library [10]. As the rows of marks appear in roughly the same horizontal bands in all images, we restrict our search to those regions. The band containing each row is extracted, converted to grayscale, noise is removed, and a binary threshold applied. The Canny edge detection operator [11] is used to locate and extract mark contours (Figure 4). The pixel location of the center of mass of each contour is computed and stored, along with the contour itself. The pixel locations of the beginning and end of each timing mark are stored as well. Known approximate mark dimensions are used to filter out erroneously detected marks. In some cases, marks are difficult to distinguish from a bright surrounding background which hinders detection. We have found that this can be remedied by passing a boxcar filter over the region prior to detection, enhancing the mark [12].

Matching Marks Across Overlapping Tiles. Scanning the PC image into 8 overlapping tiles is advantageous for storage. But because the fiducial and timing mark patterns span the entire image, tiling also complicates their identification.

After detecting timing marks in each individual tile, the modified IRIG-B pattern is decoded using the Jenk’s Natural Breaks Algorithm [13]. Fiducial and timing marks are matched in the overlap between tiles by walking the patterns over one another virtually, until the match is confirmed. Fiducial marks ids are checked by affine transformation to their known coordinates. Outliers are flagged based on their residuals from the transformation. Errors in detection, matching, and identification of marks are corrected manually. Final pixel locations of the beginning and end of timing marks and of fiducial mark centers are stored in the ISIS 3 cube labels.

The decoded timing marks are used to compute exposure rates at each column across the entire image. These are stored in a table on the ISIS 3 cube in a format comparable to run-length encoding. Each line in the table indicates a change in exposure rate and contains the column (or sample) number, ephemeralis time, and new exposure rate. Fiducial and timing mark processing have been completed for Apollo 15 PC images.

Ignoring Non-Image Data for Photogrammetric Control: When detecting and matching tie points for photogrammetric control we want to ignore the predominately black regions surrounding the image data. This speeds the process and minimizes the number of invalid black regions surrounding the image data. This speeds the process and minimizes the number of invalid tie points and false matches. After having extracted fiducial and timing marks we flag pixels in these regions to NULL using the ISIS 3 trim application so they are ignored in all future processing. The hard part is determining the region boundaries.

Upper and lower image data edges are automatically detected in a manner similar to the fiducial and timing marks, again using the OpenCV library (Figure 5). We extract the image regions where the edges are expected, convert them to grayscale, apply a binary threshold, and detect the edge with the Canny operator. Pixels in the upper and lower regions delineated by the edges are set to NULL. The pixel locations of the outermost usable timing marks define the horizontal image data extents. These are in Tile 1 (with instrument gauges) and Tile 8. Pixels outside the extents are set to NULL.

Next Steps: We are finalizing the rigorous PC model. We will then proceed to photogrammetrically control the Apollo 15 PC images, producing a digital image mosaic covering ~11% of the Moon at a pixel scale of ~2.5 m/pixel.

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