Lunar Heights from Shadows Automatically

BYRON W. RUFFIN*
Aeronautical Chart and Information Center
St. Louis, Missouri 63118

ABSTRACT: *In lunar charting, the largest portion of information for relative heights of features comes from the reduction of the measured lengths of shadow images in lunar photographs. The magnitude of this reduction program is seen in a new perspective in terms of automatic measuring instruments and computers. This program is executed through solutions using analog, digital, and hybrid systems.*

INTRODUCTION

THE PROCEDURES of charting the surface of the Moon are complicated by the fact that most of the observation data must be collected from a distance of almost a quarter of a million miles. This problem is particularly acute in regard to the topographic description of individual lunar features where it is necessary to develop accurate contours for the delineation of relief. The key solution to this problem has been the exploitation of oblique illumination phenomena, particularly the shadows cast by features at low Sun angles. Astronomers have measured this effect for over 100 years to estimate the heights of lunar mountains and the depths of craters.

The current program of production of lunar charts by the Air Force Aeronautical Chart and Information Center has demanded that these shadow reduction techniques be refined both in accuracy and efficiency. Most of this refinement has taken place through improved measurement and reduction of lunar photographs. Since an entire hemisphere of the Moon can be observed from a station on Earth, a lunar image may contain quite a large area with a wide range of perspective foreshortening and a variety of local Sun angles. New instrumentation for photographic scanning, and modern data reduction equipment, make it possible to compute relative height data automatically in a manner which is without precedent in lunar or terrestrial cartography.

THE BASIC PROBLEM

The concept of shadow reduction is a simple one, but the execution of the procedure on a large scale can be quite tedious and subject to error. In its most basic form, the problem can be described as follows.

Inasmuch as the Moon has no atmosphere, sunlight is not scattered in the sky as is experienced on Earth. For this reason, the Sun is the only intense source of light above the lunar horizon, and shadows cast by objects have extreme contrast.

After sunrise, and before sunset, when the angle of elevation of the Sun is small, there is an emphasis of relief since shadow lengths are greater than the height of the feature. The shadow/height ratio is equal to the cotangent of the solar elevation.

The shadow edges are not completely abrupt changes in light intensity, but are modified by a penumbral zone of partial shadow. The width of this zone corresponds to the angle subtended by the Sun's diameter, approximately one-half degree. The shadow edge is defined as the half-intensity point in this zone from which point the center of the Sun's disk would appear to be on the horizon.

The relative positions of the Earth, Sun, and Moon are known for any given time. Therefore, the observer is able to compute his own position, and that of the Sun, with respect to a feature casting a shadow.

The shadow image is measured in the direction of the solar azimuth in the photograph, and the true shadow length is computed from the photo scale and foreshortening angle. From the lunar coordinates of the feature, the solar elevation is determined. It is then necessary to apply only a simple trigonometric solution to establish the relative height of the point casting the shadow above the point at which it ends.

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In practice, the lunar coordinates of a particular shadow, as well as the phase and libration variables, are computed for the photograph being measured. After the shadow image has been measured, the photo scale factor and perspective corrections are applied to obtain the true length of the shadow on the lunar surface. The local solar elevation angle is used for the relative height determination.

Calibration of Measures

The main difficulties in conducting a shadow measurement program come under the category of calibration. This is a necessary program which must achieve two goals: the measures must be tied to the image points corresponding to the shadow edge; and the measured heights must be related to a lunar coordinate system. If the shadow images are measured on a linear comparator, the operator must make a decision as to the proper placement of the cross-hair for the best measurement of the shadow edge. Because the edge is diffuse in the photo image, this range of judgment may correspond to a considerable error in the height being derived.

To improve the identification of the shadow edge in the measurement process, it is possible to scan across the area with a microdensitometer, using a preselected density level in the image as the effective limit of the shadow. This technique is valid if the exact relation is known between the intensity of the light coming from the Moon and the density of the processed photograph—requiring continual calibration of exposure, processing, and the intensity-transfer function of the telescope.

Where shadow measures are made on a microdensitometer, it is necessary to relate the position of the scan line to some coordinate system at the lunar surface. The usual reference systems are based on the positions of craters distributed across the Moon's visible disk, but frequently the feature being measured is a considerable distance from one of these reference points, and the scan is difficult to locate and interpret. Ideally, the measures should be made on a microdensitometer which has the capability to relate scan data to physical distances and directions in the photographic image.

Automated Measurement and Reduction

A new program of shadow reduction has been developed at ACIC, designed around the measuring capability of the Micro-Analyzer, built by the David W. Mann Company and Data Corporation. This instrument is a sophisticated microdensitometer with a measuring stage built upon a precision x,y-linear comparator. The comparator axes are digitally encoded, such that the image coordinates of the microdensitometer spot may be recorded simultaneously with the density value. Although it is possible to use the Micro-Analyzer in a point-by-point measuring mode, its most effective use is realized, with it is operated in a scanning mode whereby density values and coordinates are recorded on the fly as the densitometer spot traces out a preset pattern in the photograph.

Measuring Procedure

A photograph is selected for measurement on the basis of scale, resolution and phase suitable for coverage of the area of interest. After the photometric calibration data have been established, the photograph is placed on the measuring stage of the Micro-Analyzer.

The first phase of the measuring program concerns the relation of the photograph to coordinates in a lunar control network. Features having known lunar coordinates are identified and their projected positions are measured in the photograph. The origin of measurement and orientation of the comparator axes are held constant throughout this and all succeeding phases of the measurement.

After the control point coordinates have been recorded, the boundaries of the area of interest are established. This permits setting the limits of X and Y-travel for the scanning mode. For simplicity in scanning and reduction, the areas are chosen as rectangular blocks within the image. The microdensitometer spot is positioned at one of the corners of the rectangle, and the other scan parameters are selected.

It is possible to vary the size of the microdensitometer spot over a wide range through combinations of fixed and variable apertures and a series of optics having different focal lengths. Thus, the spot size may be chosen to correspond to a desired fraction of the resolution of the photograph. For shadow measures in a typical lunar photograph, a spot of 15 to 20 microns is used. The spacing of the individual scan lines, and the frequency of sampling along a scan, are also left to the option of the investigator. For the most detailed studies, a complete raster tracing is made with the scan and sample separation corresponding to the dimensions of the microdensitometer spot.

The last portion of the measurement program—where the shadows are actually scanned—can be done completely automatically. After the image area limits, scan pattern, and sampling frequency have been established, the Micro-Analyzer can carry out the entire scan program without further interference by the operator. As each sample is taken, digital values of the density and the X- and Y-coordinates of the spot are recorded.

DATA REDUCTION

The data reduction program fulfills three basic tasks: the photograph coordinates are transformed into the perspective coordinates of the control points measured; the individual scans are related to positions on the surface of the Moon; the relative heights are computed for objects casting shadows. In the past, this reduction has been completed on a point-by-point basis for individual measures. The nature of the scanned densitometric data is such that the reduction phase can be handled completely in an electronic computer without the necessity of a manual interpretation step between measurement and computation.

The first stage of the reduction relates the positions of individual points within the scanned data to physical locations on the Moon. Since the time and date are known for the particular photograph, it is possible to compute the direction of perspective for the observation. The known coordinates of the lunar control features are mathematically rotated through the angle of perspective, and the positions are made to fit with the measured photo coordinates of the points through a least squares transformation. Through interpolation it is then possible to execute a control extension procedure to compute lunar latitude and longitude values for any point within the scan area of the photograph.

The next step is built around the densitometric data that constitute the output from the Micro-Analayzer scan. A matrix is established from the recorded data, with rows and columns corresponding to respective x- and y-positions. The elements of the matrix are the numerical values of density measured for the corresponding positions.

The densitometric values are then transformed into light value readings through the intensity transfer function obtained from emulsion calibration data. Thus the matrix becomes a digital plot of light values in the plane of perspective of the photograph.

Shadow edges are located within the light value array through numerical differentiation along the matrix rows (measured along the solar azimuth direction projected into the photo plane). A preselected value is used for the half-intensity point within the shadow edge, and the coordinates of this point are found through interpolation within the light differential function. Along the individual scan lines, these positions are "tagged" and become the output of a new matrix whose elements describe the pattern of shadow edges and indicate whether the edge is beginning or ending the shadow.

The photographic coordinates of the shadow extremities are transformed into lunar latitudes and longitudes through the previously established control computations. The reduction is then performed in a manner similar to present relative height calculations where the local solar elevation is computed and shadow lengths are related to the heights of features on the Moon.

For the output of this information, the computer prepares a data tape for an electronic plotter. From this tape, the plotter drafts a hard-copy manuscript that locates the scanned features on a lunar latitude-longitude grid. The beginning and end points of the shadow are identified, together with a value of the relative height between the two locations.

CONCLUSIONS

The measurement and reduction program described has been developed within the lunar charting activity at ACIC. Although no single concept or procedure within the process can be described as completely original or unique, the combination of instrumentation and data-handling represent a distinct step forward in the achievement of accuracy, speed, and versatility in fields of photogrammetry, lunar astronomy and cartography.