REMOTE SENSING FOR PLANETARY TOPOGRAPHIC MAPPING

By
SHERMAN S.C. WU

United States Geological Survey
Flagstaff, Arizona 86001 USA

ABSTRACT.- Remote sensing data from devices using a broad spectrum of wavelengths have been applied to planetary topographic mapping. A global topographic map of Mars has been compiled by the synthesis of remotely sensed data from various scientific experiments on board the Mariner 9 spacecraft and from Earth-based radar observations. Contour lines on Mars maps are also compiled by photogrammetric methods, using pictures from both Mariner 9 and Viking missions.

A global topographic map of the Moon is also being compiled using topographic information derived from various remote sensing data which include: Apollo and Lunar Orbiter photographs, laser altimeter data, lunar radar sounders, and Earth-based observations.

By using radar altimeter data transmitted from the Pioneer Venus spacecraft, a preliminary global topographic map of Venus has been compiled. For the compilation of more detailed maps of Venus, the technology of using side-looking radar stereo images is under development.

I. INTRODUCTION

Remote-sensing data play an important role in planetary topographic mapping. Topographic maps of planetary bodies are compiled by the synthesis of remotely sensed data, imaging or nonimaging, transmitted by spacecraft or received from various sensors.

A global topographic map of Mars was compiled between 1971 and 1975 by combining measurements obtained by various remote sensing devices (Wu, 1975, 1978). They include the ultraviolet spectrometer (UVS), the infrared radiometer (IRR), and the infrared interferometer spectrometer (IRIS) on board the Mariner 9 spacecraft, with Earth-based radar oppositions of Mars. The Mars topographic datum, the 0-elevation reference surface, is defined by its gravity field (Wu, 1981b), which was established from gravity data obtained by radio tracking of Mariner 9. With almost 60,000 Mars pictures transmitted back to Earth by the two Viking spacecraft, Mars is currently being systematically mapped in great detail.

By using topographic data derived from Apollo and Lunar Orbiter photographs, laser altimetry, and Earth-based observations, a global topographic map of the Moon is being compiled (Wu, 1981a). Using radar altimetry data obtained by the Pioneer Venus spacecraft, a preliminary global topographic map of Venus has been compiled (Masursky, et al., 1980). Future topographic maps of Venus will probably be compiled from synthetic aperture radar (SAR) images, using methods similar to those of conventional photogrammetry. The methods and equipment for mapping using side-looking radar stereo images are now under development (Wu and Schafer, 1980a, Wu, et al., 1980b)

Techniques for the interpretation of remote sensing data and map compilation are discussed in this paper.

II. INTERPRETATION OF REMOTE SENSING DATA

Remote sensing devices on board the spacecraft of the Mariner 9 mission provided broad topographic and thermal coverage, and measurements of parameters of the surface as well as the atmosphere of Mars. Most of the results from those experiments (UVS, IRR, IRIS, TV and S-band radio occultation) were used in topographic mapping of Mars (Wu, 1978). Sixty thousand photographs from the Viking mission make it possible to systematically map the planet Mars. The Moon, the Earth's satellite, is mapped from topographic data derived from lunar photographs and other remotely sensed data. The following sections describe interpretations of those various data.

S-band Radio Occultation. The S-band radio occultation experiments were included in both the Mariner 9 and Viking missions (Kliore, et al., 1973). There were 256 usable occultation points scattered between latitudes from +86° and -80° from Mariner 9 and about 155 points scattered over the entire Martian surface from the Viking mission. At the instant of the spacecraft orbital occultation at both entry and exit, the radii of Mars at those points were determined by recording the time immediately before and immediately after an occultation (Kliore, et al., 1972). The occultation data were received at the deep space stations at Goldstone, California, Woomera, Australia, and Cebreros, Spain.

The Mariner 9 occultation points have a wide distribution and have an accuracy range of from 0.25km to 1.10km. Therefore, they were used as control of the Mars global topographic map using Mariner 9 data (Wu, 1975). The comparison of the Mars global map with the 69 occultation points observed from the Viking extended mission (Lindal, et al., 1979), shows that the elevation differences range from -5 to +2.4km, with an average absolute difference of about 0.9km. The average arithmetic elevation difference is only -0.13 km, and only 13% of the points compared have elevation differences larger than 2km (WU, 1979). As shown in Figure 1, elevation differences are almost zero in the north and gradually increase to the south because the map was originally compiled from data that were sparse and unreliable in the south.

Ultraviolet Spectrometer (UVS). One of the objectives of the ultraviolet spectrometer experiment of Mariner 9 was to measure the composition and pressure of the martian atmosphere at the surface of Mars (Barth, et al., 1972). The reflected ultraviolet intensity is a measure of the number of atmospheric scatters. The local pressure can then be determined from these intensity measurements, and the variations of local pressure can be interpreted to measure the martian topography (Barth and Hord, 1971). There are almost 7,500 measurements of elevation provided by the UVS experiment along 39 revolutions (paths 140 to 216) of the Mariner 9 spacecraft, covering the planet Mars, from 60° south latitude to 45° north (Wu, 1975). The resolution is about 30km.

Infrared Interferometer Spectrometer (IRIS) and Infrared Radiometer (IRR). The infrared interferometer spectrometer was experimented with to infer the martian atmosphere and surface parameters which include the temperature for a vertical temperature structure. It also provides topographic information through the absorption of certain bands of CO_2. The local variations are claimed to be reliable to 0.5km, but the absolute accuracy is about 1km (Herr and Pimentel, 1969, Hanel, et al., 1970, Hanel, et al., 1972). The infrared radiometer is used to infer the thermal properties of the martian surface (Chase, et al. 1972). The data can also be used to compile a temperature map which can be correlated with topographic variations (Cunningham and Schurmeier, 1969). There are about 4,600 elevation points provided from the infrared experiment also observed along the paths of Mariner 9, covering the planet Mars from 65° south latitude to 40° north (Wu, 1975).

Earth base Radar Data. From radar observations, altitudes on the martian surface are calculated from signal time delay. In other words, variations in radar travel time to and from Mars are associated with the topographic relief

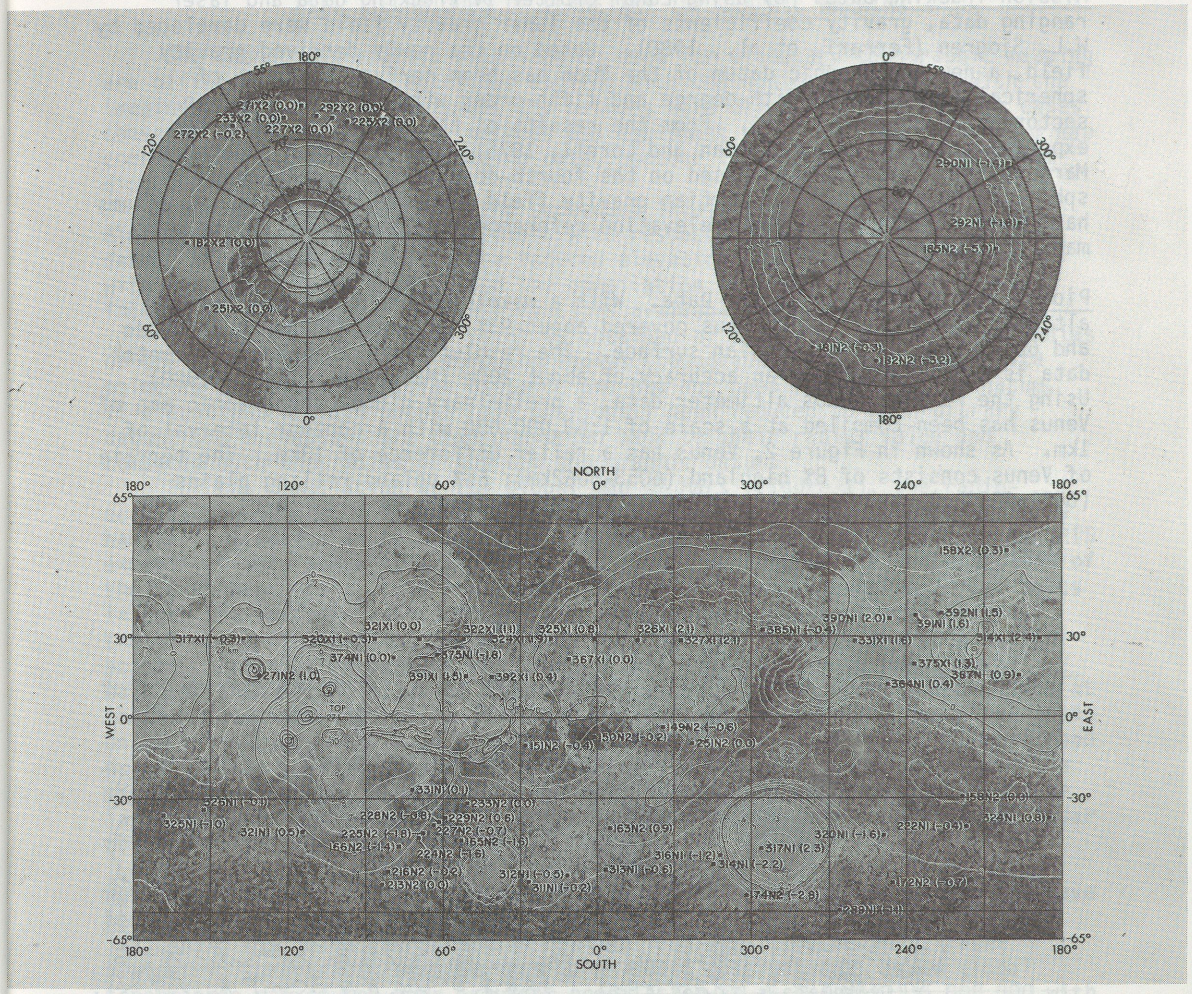

Fig. 1. GLOBAL TOPOGRAPHIC MAP OF MARS DERIVED BY SYNTHESIS OF TOPOGRAPHIC INFORMATION FROM MARINER 9 AND EARTH-BASED RADAR DATA. (The map was originally compiled at a scale of 1:25,000,000 with a contour interval of 1km. Superimposed, in parentheses, are elevation differences derived by comparing 69 elevations of occultation measurements of the Viking extended mission).

on the martian surface. The resolution of radar observations can be as small as 8 km and the relative precision of height measurements, which is simply a direct translation from precision of time measurements, ranges from 75m to 200m. The absolute accuracy of heights involves errors from both the ephemeris and the assumed figure of the planet.

More than 15,000 radar data points on Mars topography observed from Goldstone, California and Haystack, Massachusetts, were used together with various sensor data from Mariner 9 for the compilation of the Mars global map. About 2,700 points were observed from Haystack Observatory (Pettengill, et al., 1969, Pettengill and Shapiro, 1973) and more than 13,000 point from Goldstone Observatory (Downs, et al., 1973, Downs, et al., 1975). These radar data cover the martian surface approximately from 25° north latitude to 22° south. The location of the radar paths are shown in Wu's Paper (1975).

Mission-Tracking Data. By using Lunar Orbiter IV tracking data and laser ranging data, gravity coefficients of the lunar gravity field were developed by W.L. Sjogren (Ferrari, et al., 1980). Based on the newly derrived gravity field, a new topographic datum of the Moon has been derived in terms of spherical harmonics of fith-degree and fifth-order with the sixth-degree sectorial terms (Wu, 1981b). From the results of the celestial mechanics experiment of Mariner 9 (Jordan and Lorell, 1975), the topographic datum of Mars has also been derived based on the fourth-degree and fourth-order spherical harmonics of the Martian gravity field (Wu, 1981b). These two datums have been adopted to be the 0-elevation reference surface of all topographic maps of the Moon and Mars.

Pioneer Venus Radar Altimeter Data. With a wavelength of 17cm, the radar altimeter aboard Pioneer Venus covered about 93%, between 74° North latitude and 63° south, of the Venusian surface. The resolution of the radar altimeter data is about 150km with an accuracy of about 200m (Masursky, et al., 1980). Using the Pioneer Venus altimeter data, a preliminary global topographic map of Venus has been compiled at a scale of 1:50,000,000 with a contour interval of 1km. As shown in Figure 2, Venus has a relief difference of 13km. The terrain of Venus consists of 8% highland (6053-6062km); 65% upland rolling plains (6051-6053km), and 27% lowland (6049-6051km) (Masursky et al., 1980).

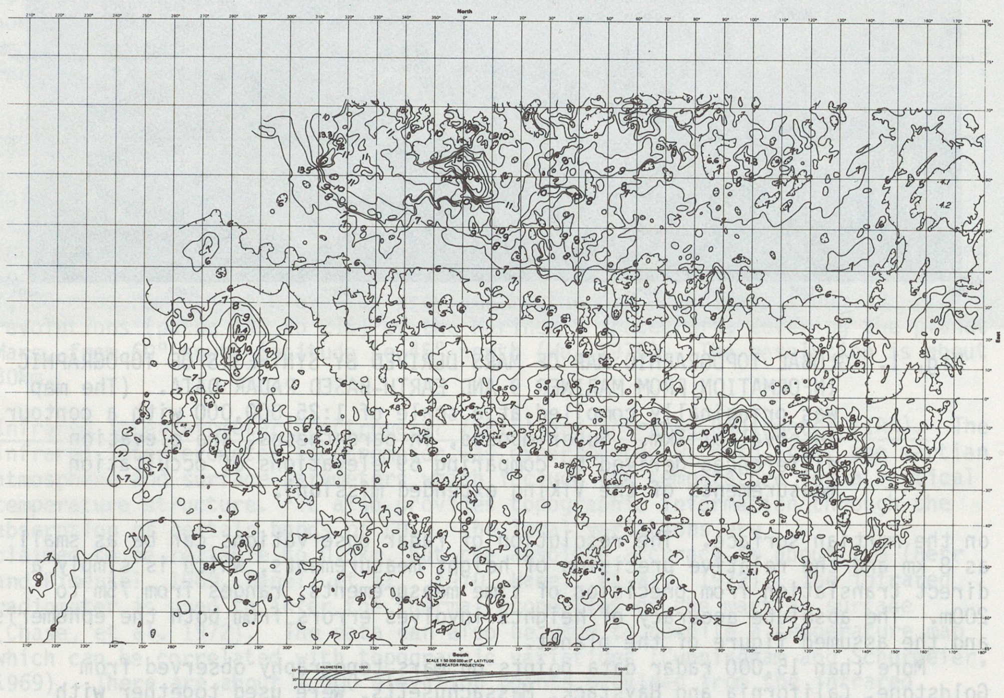

Fig. 2. PRELIMINARY TOPOGRAPHIC MAP OF VENUS--EQUATORIAL REGIION. (Map was compiled, at a scale of 1:50,000, using radar altimetry data of the Pioneer Venus mission. The contour interval is 1km. Elevations are referred to a mean radius of 6051.5km).

III. TECHNIQUES OF PLANETARY TOPOGRAPHIC MAPPING

The techniques applied with imaging data for planetary topographic mapping are different from the techniques applied with the nonimaging data. With the imaging data, some new equipment and methods were developed, and in some cases conventional photogrammetric methods and equipment were modified to perform map compilations. With the nonimaging data, contour lines are interpolated from discrete data points.

With the nonimaging data,the procedure involves the computation of the elevations of all of the data points with respect to the adopted topographic datum, the adjustment of all the reduced elevation points to be in agreement with certain control points, and the compilation of contour lines by interpolation using all of the elevations available.

The true elevation of a point is obtained by comparing the observed radius of the topography with the computed radius (topographic datum), if the data point is the observed radial distance and has not been reduced to the datum. If elevations of data points have previously been reduced to an arbitrary datum, the elevations are then converted back to their radius value and compared with the radius of the new topographic datum.

For the compilation of the global map of Mars (Figure 1), the radio-occultation points of Mariner 9 were used as control points. Since Mariner 9 had an inclination angle of 65°, all of the data from both the UVS and the IRIS experiment were somewhat oriented in the north-south direction and the paths of the Earth-based radar data are exactly in the east-west direction in two belts in both the northern and southern hemispheres, the adjustment procedure is therefore to first adjust the radar data by matching them to the occultation points, then all the data of the UVS and IRIS elevations were adjusted by matching them to the adjusted radar points as well as the occultation points at their mutual intersections. This was done like laying down railroad ties (data on paths) onto two railroad tracks (radar data belts). Contour lines were then drawn by interpolation using all of the adjusted elevations. Figure 1 is the map compiled by this technique. This map is currently being updated with the large amounts of imaging data from the Viking mission and with additional radar observations.

In order to use the Viking Orbiter photographs, which have extremely narrow fields of view, for systematically mapping Mars, special techniques have been developed (Wu, et al., 1982).

Using topographic information derived from lunar photographs, laser altimetry, lunar radar sounder, and Earth-based observations, a new global topographic map of the Moon is under compilation at a scale of 1:5,000,000 with a contour interval of 500 meters. An intermediate product of the compilation is contour maps compiled by photogrammetric methods, using metric photographs of the Apollo 15, 16, and 17 missions (Wu, 1981a). Maps were compiled using the same format as the existing NASA Lunar Planning Charts and therefore the map scale is 1:2,750,000 with a contour interval of 500 meters. Figure 3 is an example of the eastern half of the map LOC-3 which covers an area between the longitudes 140°E to 40°W.

IV. DISCUSSIONS

The data used for planetary topographic mapping is entirely generated from remote sensing. Map precision depends upon the sensitivity of the sensor devices and the methods used to interpret the remote sensing data. New mapping techniques and the modification of existing mapping techniques are continually in progress. For instance for the mapping of Venus in great detail, topographic mapping using side looking radar images is under development.

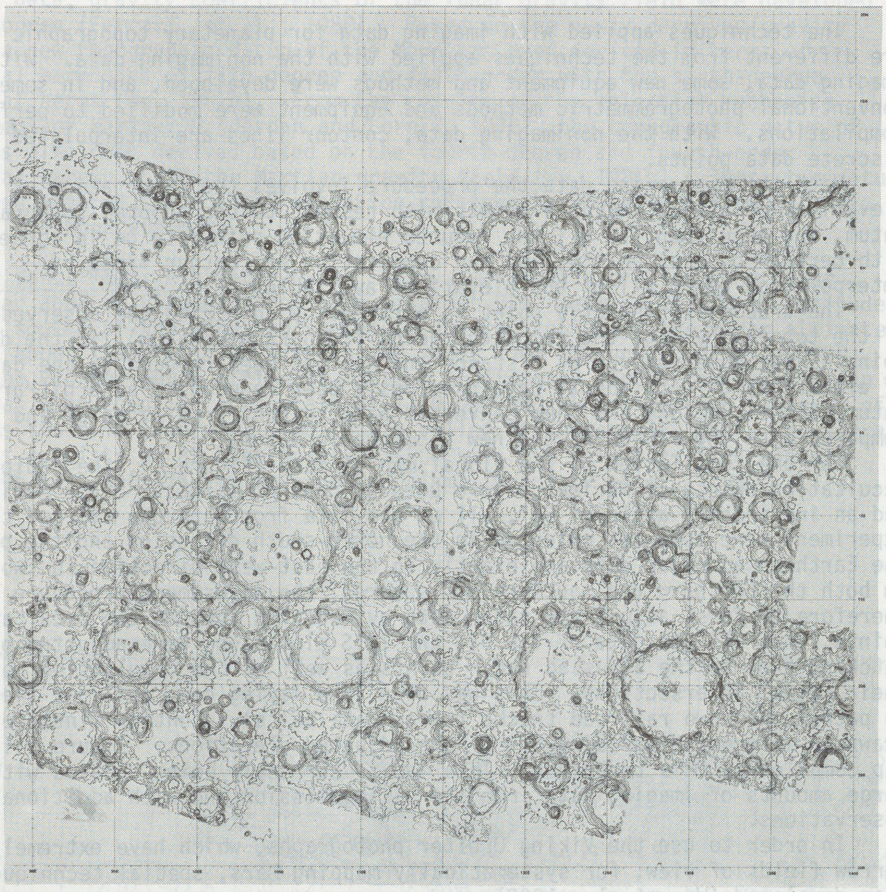

Fig. 3. TOPOGRAPHIC MAP OF THE MOON (EASTERN HALF OF LOC-3). (The map was compiled at a scale of 1:2,750,000 using about 180 stereo models of metric photographs from Apollo 15, 16, and 17 missions. Contour interval is 500m).

REFERENCES

Barth, Charles A., and Hord, Charles W., 1971, Mariner 9 ultraviolet spectrometer: Topographic and polar cap, Science, vol. 173, no. 3993, pp 197-201.

Barth, Charles A., Hord, Charles W., Stewart, A. Ian, and Lane, Arthur L., 1972, Mariner 9 ultraviolet spectrometer experiment: Initial result, Science, vol. 175, no. 4019, pp. 309-312.

Chase, S. C. Jr., Hatzenbeler, H., Kieffer, H. H., Miner, E., Munch, G., and Neugebauer, G., 1972, Infrared radiometry experiment on Mariner 9, Science, vol. 175, no. 4019, pp. 308-309.

Cunningham, N. W., and Schurmeier, H. M., 1969, Introduction in Mariner Mars 1969: A preliminary report, Natl. Aeron. and Space Admin., NASA SP-225, pp. 1-36.

Downs, G. S., Goldstein, R. M., Green, R. R., Morris, G. A., and Reichley, P. E., 1973, Martian topography and surface properties as seen by radar: The 1971 opposition, Icarus, vol. 18, no. 1, pp. 8-21.

Downs, G. S., Reichley, P. E., and Green R. R., 1975, Radar measurements of martian topography and surface properties: The 1971 and 1973 oppositions, Icarus, vol. 26, no. 3, pp. 273-312.

Ferrari, A. J., Sinclair, W. S., Sjogrem, W. L., Williams, J. G., and Yorder, C. F., 1980, Geophysical parameters of the Earth-Moon system, Jour. Geophys. Res., vol. 85, no. B7, pp. 3939-3951.

Hanel, R. A., Conrath, B. J., Hovis, W. A., Kunde, V., Lowman, P. D., Prabhakara, C., and Schlachman, B., 1970, Infrared spectroscopy experiment for Mariner Mars 1971, Icarus, vol. 12, no. 1, pp. 48-62.

Hanel, R. A., Conrath, B. J., Hovis, W. A., Lowman, P. D., Pearl, J. C., Prabhakara, C., and Schlachman, B., 1972, Infrared spectroscopy experiment on the Mariner 9 mission: Preliminary result, Science, vol. 175, no. 4019, pp. 305-308.

Herr, K. C. and Pimentel, G. C., 1969, Infrared spectroscopy of Mariner 9: A preliminary report, Natl. Aeron. and Space Admin., NASA SP-225, pp. 83-96.

Jordan, J. F., and Lorell, J., 1975, Mariner 9: An instrument of dynamical science, Icarus, vol. 25, no. 1, pp. 146-165.

Kliore, A. J., Cain, D. L., Fjeldbo, G., and Seidel, B. L., 1972, Mariner 9 S-band martian occultation experiments: Initial results on the atmosphere and topography of Mars, Science, vol. 175, no. 4019, pp. 313-317.

Kliore, A. J., Fjeldbo, G., Seidel, B. L., Sykes, M. J., and Woiceshyn, P. M., 1973, S-band radio occultation measurements of the atmosphere and topography of Mars with Mariner 9: Extended mission coverage of polar and intermediate latitudes, Jour. of Geophys. Res. vol. 78, no. 20, pp. 4331-4351.

Lindal, Gunnar, F., Hotz, Henry, B., Sweetnam, Donald N., Shippony, Zvi, Brenkle, Joseph P., Hartsell, Gene V., and Spear, Richard T., 1979, Viking radio occultation measurements of the atmosphere and topography of Mars: Data acquired during 1 martian year of tracking, Jour. of Geophys. Res. vol. 84, no. B14, pp. 8443-8456.

Masursky, Harold, Eliason, Eric, Ford, Peter G., McGill, George, E., Pettengill, Gordon H., Schaber, Gerald G., and Shubert, Gerald, 1980, Pioneer Venus Radar Results: Geology from images and altimetry, Jour. of Geophys. Res. vol. 85, no. A13, pp. 8233-8260.

Pettengill, G. H., Counselman, C. C., Rainville, L. P., and Shapiro I. I., 1969, Radar measurements of martian topography, Astron. Jour., vol. 74, no. 3, pp. 461-482.

Pettengill, G. H., and Shapiro, I. I., 1973, Topography and radar scattering properties of Mars, Icarus, vol. 18, no. 1, pp. 22-28.

Wu, Sherman S. C., 1975, Topographic mapping of Mars, 1975, U. S. Geological Survey Interagency Report: Astrogeology 63, 193p.

Wu, Sherman S. C., 1978, Mars synthetic topographic mapping, Icarus, vol. 33, no. 3, pp. 417-440.

Wu, Sherman S. C., 1979, Photogrammetric portrayal of Mars topography, Jour. of Geophys. Res. vol. 84, no. B14, pp. 7955-7959.

Wu, Sherman S. C., 1981a, New global topographic mapping of the Moon in Abstract book of the 12th Lunar and Planetary Science Conference, part 2, pp. 1217-1218.

Wu, Sherman S. C., 1981b, A method of defining topographic datums of planetary bodies, International Review--Annales de Geophysique, Centre National de la Recherche Scientifique, Numero 1, AGEPA 7-37 (1), pp. 147-160.

Wu, Sherman S. C., and Schafer, F. J, 1980a, Side-looking radar using analytical plotters in Proceedings of the Analytical Plotter Symposium and Workshop of the American Society of Photogrammetry and Remote Sensing, pp. 442-444.

Wu, Sherman S. C., Schafer, F. J. and Barcus, L. A., 1980b, VOIR photogrammetry, Report of Planetary Geology Program-1980, U. S. Natl. Aeron. and Space Admin. Tech. memo. 82385, pp. 463-465.

Wu, sherman S. C., Elassal, A. A., Jordan, Raymond, and Schafer, F. J., 1982, Photogrammetric application of Viking orbital photography, Planetary and Space Science, vol. 30, no. 1, pp. 45-55.

The Expar

This pa
ware Systen
data. The p
which the a
The sys
-Tape ha
-Statist
-Image e
-Trainir
-Supervi
-Unsuper
-Cleanir
-Accurac
-Result
In this
the preproc
greater ela
The sys
monitoring.
practical w

INTRODUCTIC

One app
Scanner (MS
report disc
processing
at the Depa
and at the
The pro
for image d
following t
the progran
1. The
2. It s
with
Proceed
was designe
subject. Fo
hancement, t
unsepervise
optimum me
rent methoc