Lunar Laser Ranging Data Deposited in the National Space Science Data Center: Filtered Observations for 1969 September through 1970 June and Unfiltered Photon Detections for 1970 July through December

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I. Introduction

A revolution is occurring in astrometry. Perhaps the most striking example is the technique of laser ranging to a reflector fixed on a celestial object, partly because the attainable precision is so high that the data can tell us as much about Earth as about the observed object. The Apollo astronants have now placed three widely separated reflector arrays on the Moon as a part of the Lunar Laser Ranging Experiment (LURE), the participants in which are listed in the Acknowledgements.

Although the groundwork in the experiment began much earlier, the data-taking process did not begin, of course, until 1969 July, when the Apollo 11 mission was flown. Success in recognizing returns from the reflector was not achieved until the following month. For many months there-after, various causes contributed to a very low data rate. It was not until 1970 April that regular successes became common.

From the experiment's inception, the LURE Team has recognized the obligation to make these data available in a reasonably usable form, and we have agreed upon a time-schedule that strives for a fair compromise between timely release and priority of the members of the LURE Team. Because of the unforseeable but unsurprising start-up difficulties in an experiment of this nature, the present submission is the first to achieve the normal schedule. This report is the documentation to be used in conjunction with the deposition in the National Space Science Data Center (NSSDC) of the filtered data obtained during laser ranging operations between the McDonald Observatory and the reflector at Tranquility Base during the interval 1969 September through 1970 June and the unfiltered photon detections for the succeeding six months. These two blocks will be discussed in more detail in subsequent sections of this memorandum.

II. Observatory and Reflector

The laser ranging equipment is mounted on the 272 cm reflector at the McDonald Observatory, Fort Davis, Texas. The physical installation has been so thoroughly described in the literature (e.g. Silverberg and Currie 1971) that it seems unnecessary to dwell on it here. The nominal coordinates presently recommended for this instrument, based on high-order land survey ties to the SAO Organ Pass Tracking Station, are

geocentric radius	ρ=6374.671 km
east longitude	λ=+255.97776 degrees
geocentric latitude	ϕ'=+30.50316 degrees

These refer to the intersection of the polar and transverse axes of the telescope. The center of the primary mirror, as the telescope tracks across the sky, describes a circle of radius 305 cm whose plane is normal to the polar axis.

The present data all refer to the reflector at Tranquility Base, whose nominal coordinates are

selenocentric radius	ρ=1735.567 km
east longitude	λ=+23.485 degrees
latitude	β=+0.642 degrees

as supplied by NASA/MSC during tracking operations during the Apollo 11 mission.

III. Filtered Data

The photon detections for 1969 September through 1970 June have been submitted to a data filtering procedure developed at the University of Texas. This process is based on the assumption of the linearity of Ø-C residuals over a relatively short time interval and relies on Poisson statistics for establishing a level of confidence in a collection identified by the filter. Application of the process resulted in the identification of 120 observations during the subject interval. Additional points may be added to this set later, as some of the early operations were recorded on paper tape, and the corresponding photon detections are not yet available to us.

The potential user should be aware that the laser cannot be relied upon to produce a simple pulse shape. There sometimes is a complex and/or biased structure within the pulse. Therefore, residuals derived from signal photons are not necessarily expected to show a Gaussian distribution.

The observational uncertainties for data prior to 1970 March 16 are arbitrarily degraded to a high level, reflecting the discovery of severe electronic problems that caused apparently irrecoverable timing errors during this period. The uncertainties assigned subsequent to that date are based on the sum of the pulse half-width and the measured uncertainty in calibrating the electronic system. The calibrations were performed by E.C. Silverberg.

IV. Unfiltered Photon Detections

It is most important that the potential user observe the designation "unfiltered". By this, we mean that the real data are heavily interspersed with noise photons from any of the various sources of stray light. Any attempt to use these data in a simple Gaussian application would probably result in a solution closely adhering to the prediction ephemeris used to control the detector range gating. Some filtering process needs to be applied to these data before effective use can be made of them. Such filtering is now underway at the University of Texas at Austin, and the filtered data will also be deposited with NSSDC in 1972 July, but the unfiltered data may be of direct utility or interest to those potential users who may wish to replace our filter criteria with their own.

V. Data Description and Card Formats

The data are contained on a magnetic tape written in card image format, through FØRTRAN, using a CDC 6600 computer. It is written with even parity at 800 bpi. The formats have been chosen to conform with a currently-proposed standard (Mulholland 1971). Two types of cards are present, distinguished by an alphabetic character in column 1: The letter Z designates a "run" card, giving environmental and operational parameters for a series of shots. These will not customarily be required for application of the range data, but serve to provide information on the observing conditions and the state of the equipment. Most users will find them helpful only as separators between observing sessions. The letter P in column 1 represents a "shot" card, containing the result of a single laser firing. The two formats are described below.

Run card

Read a run card with, for example, the FØRTRAN statements

READ (x,1) (A(J),J=1,22)

1 FØRMAT(A1,3I,D10.3,1X,I7,I3,3I2,3X,I3,I5,5I3,A5,2I3,2I4,2I2)

ignoring for the moment that we have mixed our variable modes.

Then the variables A will contain the following information:

A(1)	=Z
A(2)	=711 (3-digit observatory code)
A(3)	Julian date of beginning of run
A(4)	Clock epoch error, sec x 10^6
A(5)	Ambient temperature, °C
A(6)	Ambient relative humidity, % saturation
A(7)	Wind speed, km/hr
A(8)	Atmospheric seeing, arc sec x 10
A(9)	laser energy, joules x 10
A(10)	laser frequency, Hz x 10^{10}
A(11)	pulse length, sec x 10^{10}
A(12)	observational resolution, sec x 10^{10}
A(13)	photomultiplier dark count, kHz
A(14)	Moon count rate, kHz (Gross)
A(15)	Star count rate, kHz (Net)
A(16)	Calibration star identification
A(17)	Filter spectral width, Å x 10
A(18)	Filter spatial width, arc sec x 10
A(19)	Number of shots fired this run
A(20)	Year
A(21)	Month
A(22)	Day

The sense of the clock error is that it is to be subtracted from the clock time to give the true UTC time. This correction has not been applied to the observation epochs on the shot cards.

Shot card

Similarly, again ignoring variable mode questions for the sake of illustration, read a shot card with

READ(X,2) (B(J), J=1,17)

2 FØRMAT(A1,I3,D17.10,I5,1X,I1,A1,I1,D12.10,I5,I6,I5,~~4X,I4~~ 3X,I5,
I1,I5,I4,2I2)

Then the variables B will contain the following information:

B(1)	=P
B(2)	=011 (body identifier)
B(3)	Julian date of observation
B(4)	=71110 (observatory code)
B(5)	=0 (reflector code for Tranquility)
B(6)	=L (observation type)
B(7)	=1 (epoch time base is UTC)
B(8)	Observed time delay, seconds
B(9)	Observational uncertainty, seconds x 10^{10}
B(10)	Electronic calibration delay, seconds x 10^{10}
B(11)	Geometric delay, seconds x 10^{10}
B(12)	Clock frequency offset from UTC, parts in 10^{11}
B(13)	=1 (time delay time base is UTC)
B(14)	Ambient pressure, mbar x 10
B(15)	Year
B(16)	Month
B(17)	Day

The electronic and geometric delays refer to the equipment response times and the reduction to the geometric fixed point, respectively, and are to be subtracted from the observed time delay.

A word of warning is in order to the unwary users. During the report interval, many of the specified data items discussed above are not available. In the card images, a blank field is a "no information" indicator. Actual null values will be represented by zero punches. This is particularly important for clock epoch error. No clock data are presently available, although Currie (1970) estimates that the "actual epoch should be known to the order of 10 μsec or better."

IV. Acknowledgements

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V. References

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