Analysis of Lunar Orbiter Images Recovered from Analog Tape

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A Study of the Value of Original Data Sources for Space Science Data

In 1966-1967 NASA sent five spacecraft to the Moon to map potential landing areas for the Apollo program as well as for the first global map of a planetary body other than the Earth. Lunar Orbiter's I-III were in equatorial orbits with a periselene of ~44km and an aposelene of ~4000 km. Lunar Orbiter's IV-V were in polar orbits at various altitudes for global mapping and follow up on LO-I-II. Using a visible light 70mm film camera, each spacecraft took ~210 medium resolution and ~210 high resolution images.

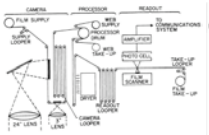
The original Lunar Orbiter analog tapes are in a remarkable state of preservation which has allowed a recovery of the data to the limit of the original film quality on the spacecraft. With modern software and computer methods, along with the preservation of the original data sources can allow future researchers to improve the quality of older data sets to provide new science from old sources. This "technoarcheology" represents a new resource for providing time based comparisons of planetary data.

Lunar Orbiter Cameras

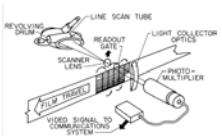
The LO cameras, with focal lengths of 80 mm and 640 mm mapped the Moon with maximum resolutions of 5-7 meters and 0.8-1.2 meters respectively. This resolution was not equaled until the LRO mission presently in orbit.

LO Cameras and Ground System

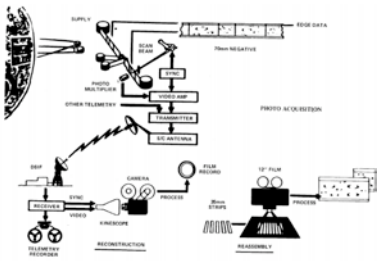
The LO cameras used 70mm SO-243 film to record images. These were developed, scanned, transmitted back to Earth where they were recorded on magnetic tape and 35mm film.



LO MR and HR Film System



LO Film Scanning Illustration



LO onboard scanning to 2" magnetic tape and GRE 35 mm film.

The original LO 70mm film was processed on board the spacecraft and then scanned by a 5 micron monochromatic light beam fed into a photomultiplier. The output was first vestigial sideband modulated (VSB) then Frequency Modulated (FM) onto a 2295 MHz carrier. On the ground at Woomera, Madrid, and Goldstone, the signals were recorded on 2" analog magnetic tape before demodulation to maximally preserve signal integrity. In parallel, the incoming signal was demodulated and displayed to a kinescope. The kinescope images were filmed by a 35 mm Ground Reconstruction Equipment (GRE) camera one 70mm scan (framelet) at a time. The framelets were assembled into an image and photographed on 35mm film, which was developed and printed on 20"×24" paper. These images were used in conjunction with the 2" analog tapes to choose the landing sites for Apollo 11,12, and 14.

Hansen, T.P. Guide to Lunar Orbiter Photographs, NASA SP-242, NASA Scientific and Technical Information Office, Washington D.C., 1970

The Boeing Company, Lunar Orbiter I Photographic Mission Summary, NASA CR-782, April 1967

Lunar Orbiter Image Recovery Project (LOIRP)

The LOIRP project was founded to recover the original highest resolution data from the 2" analog tapes. The tape data has higher dynamic range than the GRE Film and thus provides a high value for data recovery at original resolution.

Three Questions

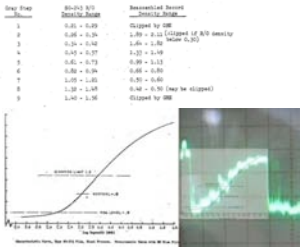
1. Can the original FR-900 Tape Drive Be Refurbished?

The only surviving tape drives were saved by NASA retiree Nancy Evans. They were brought to Ames and restored by the LOIRP team.

2. After 43+ years, are the tapes still playable with good data?

The tapes were stored at the National Archives for 20 years, then at JPL for an additional 22 years. NASA archived the tapes in Mu metal cans and the tapes were stored in climate controlled conditions. The tapes were in excellent condition. All tapes so far played have good analog data.

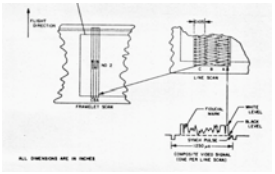
3. Is the image quality greater than the GRE Film?



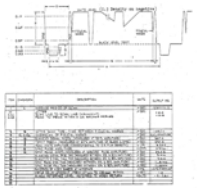
The original GRE film clipped the blacks and whites, reducing the dynamic range to 6-7 bits. The 70mm spacecraft film had 10 bit dynamic range. The LOIRP tape digitization recaptures the full dynamic range of the 70 mm film transfer function.

The Image Restoration Process

The Lunar Orbiter image format is extensively documented and this assisted in the restoration process.

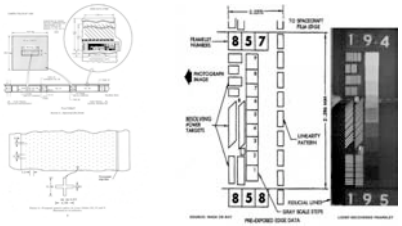


LO Film Scan as recorded on tape



Individual Scan Line Specification

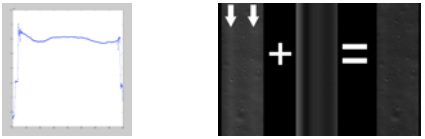
The analog data on the tapes is stored in exactly the manner as it was scanned on the spacecraft. Each individual line follows an exact specification that guides reconstruction.



Each framelet has a pre exposed calibration edge data strip to provide proper reconstruction of the framelet and to provide quality assessment.

Correction for Readout Signature

The readout scanner utilized onboard the Lunar Orbiter spacecraft employed a phosphor-covered anode bombarded by an electron beam to focus a spot of light on the developed film. This light was modulated by the density of the image and read by a photomultiplier tube. The readout system caused an artifact, manifesting as a regular vertical banding within each image. To correct this artifact a readout signature template is extracted by applying an averaging method across all lines within the framelet. This correction works very well on typical image data, where surface features are small relative to the width of a framelet and uniformly distributed.



Plot of spacecraft readout signature (left) with graphical representation of correction template and corrected framelet (right).

Results

LO-102-H

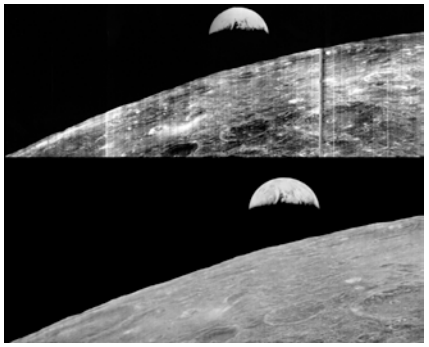


Figure 1: Original GRE Film (Above), and LOIRP Reproduction (Below)

LO-162-H3 Detail

Figure 2: Reproduction of the Detail of the Central Uplift of Copernicus, GRE (Above), LOIRP Reproduction (Below)

Our study has conclusively shown that when there is contrast in a scene that the Lunar Orbiter images derived from the original analog tapes show improved contrast ratios. The original 1000 to 1 contrast ratio of the spacecraft 70mm film is preserved and provides the highest fidelity comparison between Lunar Orbiter images and modern lunar missions.