COMMISSION IV

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STEREOSAT: A GLOBAL DIGITAL STEREO IMAGING MISSION

ABSTRACT

During the last four years a global stereo imaging mission has been under study by NASA-JPL. The requirement for stereo images stems mainly from the resource exploration sector. This group has learned the value of the synoptic view from orbit through use of Landsat data, but has felt that many times more information is available by the use of stereo.

The objectives of the Stereosat mission are to (1) Obtain world-wide, cloud-free stereo coverage at two base-height ratios and with a ground IFOV of 15 m. (2) Obtain stereo data in digital form that can be merged with monoscopic digital terrain models derived directly from the image data stream. A decision on the implementation of the mission has not been taken.

Introduction

Stereoscopic images are the basic data used by all photointerpreters and map makers. To date, however, very little stereo data has been obtained by space platforms. Landsat images are available for almost all the land surface of the Earth but only a small portion of the coverage yields stereo, and the vertical exaggeration in these data is very small. To meet the need for stereoscopic image data the concept of a free-flying satellite system using electronic scanning imaging system was developed. The following is a discussion of the technical parameters and rationale included in one approach to such a mission named Stereosat.

Geological Mapping Requirements

The Stereosat concept has been most heavily promoted by those in the geological disciplines. The major reason is that geologists are interested in extrapolation into the subsurface. Monoscopic data, such as provided by Landsat, does not yield quantitative information about the dips of stratigraphic units or the types and offsets of faults. The keen interest in Stereosat is based on the need for three-dimensional data.

A geologic map is a two-dimensional representation of a three-dimensional model of the Earth's surface and subsurface to an appropriate depth. The geologic map includes information on rock units, ages of the units, surface and subsurface contours, and structure, such as folds, faults, and joints. On the map, subsurface extrapolation is depicted by the presentation of cross-sections. Without the third dimension provided by stereo, extrapolation into the subsurface is not possible.

Geologists have used stereo air photos for more than 40 years. Since World War II, no photogeologist would make an intepretation without stereo photogaphy. Landsat provided a kind of data base not previously available and interpretation had to be done without the advantage of stereo except within the sidelap regions. The Landsat sidelap stereo develops only a very small vertical exaggeration (base-to-height ratios usually < 0.1). However, a great deal more confidence in interpretation can be derived even with the use of poor stereo. Stereosat will combine the advantages of the regional overview now employed by Landsat users with one-fifth the IFOV equivalent to 25 times higher areal resolution, and ten times greater vertical exaggeration.

Digital Data Bases

Digital computing has permeated to every corner of our society. In scientific endeavors, the manipulation and use of digital data is still expanding rapidly. In the area of geology and geophysics, no modern data collection system is built today that does not have digital output. The preservation of quality and ease of data manipulation require that digital techniques be used.

Great quantities of data are now being digitized and placed in data bases. These data bases contain items such as geologic maps, topographic maps, seismic data interpretation, magnetic and gravity data, and geochemical data. One of the more difficult and expensive operations is that of placing digital topographic information into data bases. These data are derived from digitized topographic maps in general and contain numerous errors and inconsistencies. Stereosat has the potential for delivering data in digital form which can be correlated directly to produce digital topographic maps. Although the implementation of direct digital correlation is not yet completely understood, it holds potential for developing topographic maps from Stereosat at scales of approximately 1:100,000. Digital maps to this scale do not presently exist for most parts of the world.

Stereosat Mission Concept

The requirements for a Stereosat mission developed during the study were threefold.

1. Obtain global, cloud-free stereo image coverage of the Earth's land masses at two base-height ratios and with a ground IFOV of 15 m.

2. Obtain stereo data in digital form that can be merged with monoscopic Landsat multispectral data.

3. Develop the potential for the production of digital terrain models directly from the image data stream.

System Lifetime Considerations

The requirement for global cloud-free coverage automatically necessitates a free-flying satellite system (1). The swath width of coverage and cloud cover statistics then determine the lifetime requirement for the spacecraft.

Figure 1 shows a contour plot for the U.S. of the probability of 0 to 10 percent cloud cover at the time of a Landsat pass. The statistics were developed from six years of data from Landsat for 427 path-row intersections. Between 150 and 170 passes for each point were obtained.

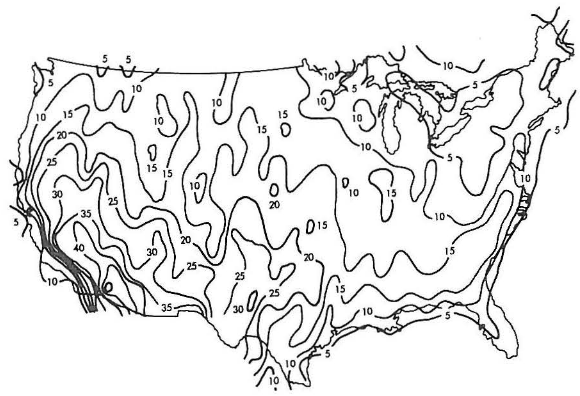

Fig. 1 Percent probability of 0 to 10% cloud cover for any overflight.

From these data it is also possible to calculate the number of passes required to obtain, for a given probability, one 0 - 10 percent cloud cover image. Figure 2 shows a cumulative plot of U.S. coverage as a function of the number of satellite overpasses required. The 75% probability, obtained from the application of binomial statistics to the cloud-cover data, most closely matches the actual cumulative coverage experience with Landsat. Twenty-two passes are required to obtain 90% cumulative coverage. Unfortunately, this type of analysis is only possible for areas within reach of a Landsat ground station and for which a continuous data set has been acquired over a number of years. However, the U.S. data can be used as a guide in developing satellite lifetime requirements.

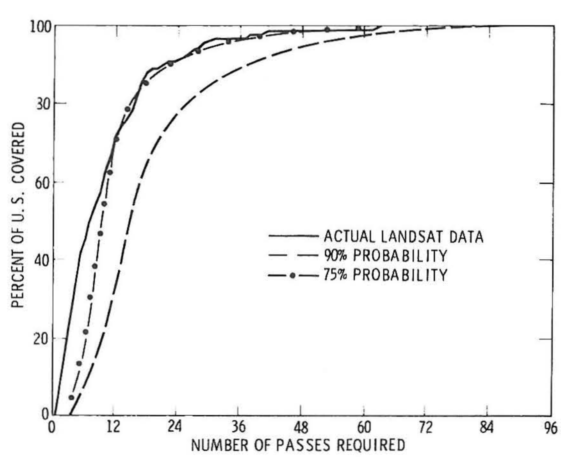

Fig. 2 United States coverage; 0 to 10% cloud cover, 427 stations.

Instrument Parameters

The choice of a long-lived free-flying satellite requires the use of an electronic imaging system. For Stereosat a pushbroom imaging system was chosen, using a silicon, line-array detector. The operation of such a system is shown in Figure 3. Three pushbroom cameras are used, one vertical and two angled fore and aft 23° off nadir, to create stereoscopic images with base-height ratios of 0.49 and 1.0. The geometry of the system is shown in Figure 4. Convergent rather than perspective stereo images are created with the pushbroom system, and the parallax, which yields the elevation information, is one-dimensional along the spacecraft ground track.

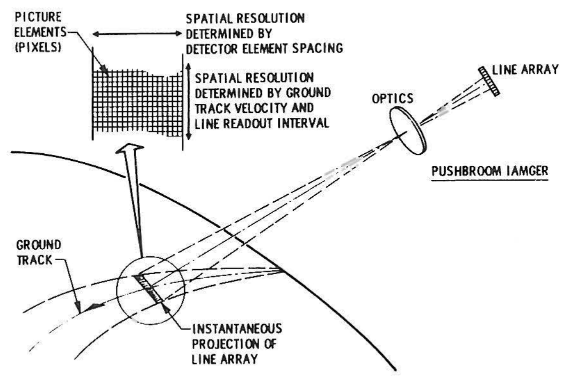

Fig. 3 Pushbroom imaging using line-array detectors.

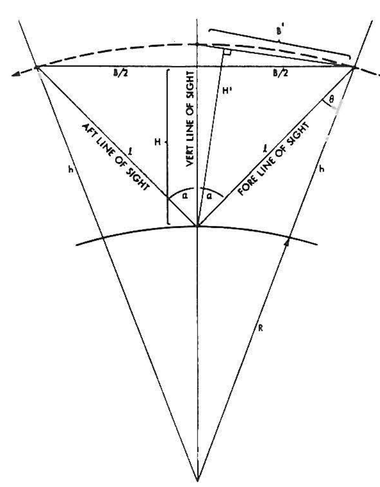

Fig. 4 Stereosat viewing geometry.

Data handling considerations, including the availability of an on-board tape recorder, set a limit on the data rate of approximately 33 Mbs. Figure 5 shows a set of parametric curves used in determining IFOV and swath width as well as the number of detector elements necessary. An IFOV of 15 m was deemed required to produce adequate stereo resolution for photointerpretation. The resulting instrument characteristics are shown in Table 1.

Table 1

STEREOSAT
INSTRUMENT CHARACTERISTICS

CONFIGURGATION:	SINGLE INSTRUMENT SYSTEM WITH THREE CAMERAS
SENSOR:	TWO 2048 ELEMENT LINEAR ARRAYS PER CAMERA (4096) ELEMENTS PER LINE)
OPTICS:	FORE AND AFT CAMERAS, 775 mm FOCAL LENGTH VERTICAL CAMERA, 705 mm FOCAL LENGTH
PIXEL INSTANTANEOUS FIELD OF VIEW	2.2 μ RADIAN → 15 m
SWATH WIDTH	61.4 km
LINE TIME:	22.2 msec
PIXEL RATE - PER CAMERA:	1.85×10^6 PIXEL/SEC
RAW DATA RATE PER CAMERA:	11.05×10^6 bps

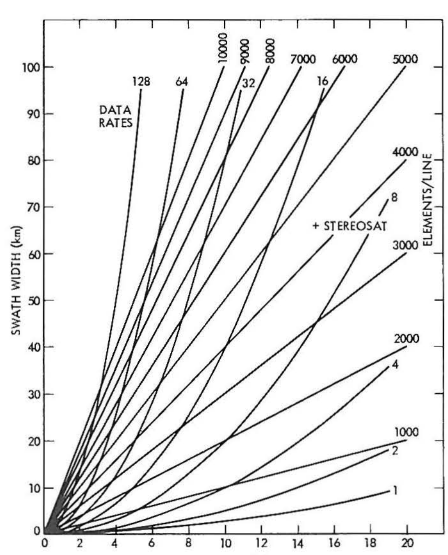

Fig. 5 Swath width versus resolution.

Spacecraft Parameters

The spacecraft chosen was a Multimission Modular Spacecraft (MMS). This spacecraft will be launched into a sun synchronous orbit and maintain a 48 day repeat cycle. The aforementioned requirement for 22 passes to obtain global coverage yields a mission lifetime of 3 years.

A critical requirement for adequate heighting accuracy is spacecraft attitude control. An attitude drift rate of 10^{-4} deg/sec in all axes is maintained. This rate yields a ± 1 picture element internal accuracy in any 60 x 60 km image frame. Approximately 8 seconds are required to produce one image. The interval between fore and aft frame coincidence on the ground is 90 seconds so that rotation and translation of the frames are required to bring the stereo pair into coincidence.

Yaw steering is required to compensate for Earth rotation. The sign of the yaw drift reverses at the equator. Yaw compensation can be accomplished for two cameras simultaneously. However, errors are introduced if a compromise compensation for three cameras is attempted.

Geometric Accuracy Considerations

Geometric distortions are introduced into any type of scanner image acquired. Figure 6 illustrates some of the intraframe aberrations expected for Stereosat. Some aberrations are more serious than others in that some affect the capability for quantitative analysis where others may affect only the aesthetics of the products.

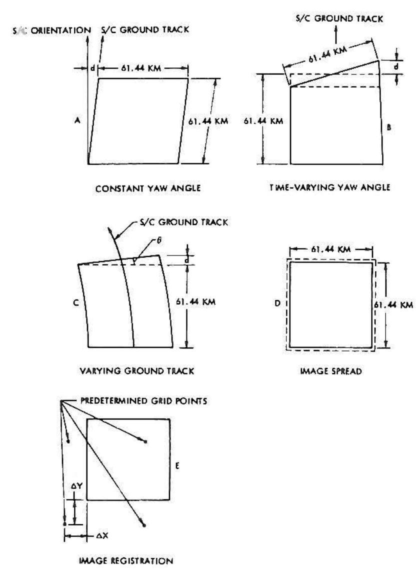

Fig. 6 Single-frame aberrations.

Figure 6A illustrates the image configuration due to a non-zero yaw angle between the camera platform and the satellite ground track. If the yaw angle θ is constant, the image lines remain parallel and no serious impact on photo analysis is expected to result. However, d greater than 200 pixels exceeds specified sidelap limits. A similar aberration results from a constant roll rate error.

Figure 6B shows the image line rotation that results from a time-varying yaw angle relative to the satellite ground track. This aberration results in pixel distortion that could affect image interpretation. The mission objective is to present a final image with image line rotation θ less than 0.25 milliradian where needed for quantitative analysis.

The aberration shown in Figure 6C results when the ground track does not follow a great circle route on the Earth even though the camera platform is aligned with the ground track. The resulting aberration is similar to that of a time-varying yaw angle.

Image spread, illustrated in Figure 6D, is a form of image displacement that alters image size. It can occur along-track, cross-track, or both, depending on the error source. Cross-track image spread will result from Earth curvature, for example, but, in this case, it is considered as "data" rather than an aberration. Along-track image spread can result either from a pitch rate error or from a pitch attitude error changing the nominal slant range. In either case, an image aberration results.

A spacecraft altitude displacement from the nominal value results in image spread in both directions. A sizable altitude displacement can occur from either the geometrical or the gravitational effects of Earth oblateness or from an incorrect orbit shape or orbit orientation. Image spread can hamper image interpretation and the capability will exist to limit the image spread in the final image product to less than one pixel in any direction.

It is realistic to expect each photo triplet to be registered within about 5 km of the predetermined grid points set up for cataloging purposes. Figure 6E illustrates image registration relative to the grid points. For the baseline camera mechanization, the cross-track displacement ΔX for a given frame will reach, at times, up to about 4 km and the along-track displacement ΔY will generally be less than 3 km.

A spot heighting accuracy of 30 m or better can be expected by using conventional photogrammetric techniques. With an absolute pointing accuracy of 0.1° and without control points, 100 m contour maps can be constructed equivalent to a scale of 1:250,000. Images at a scale of 1:50,000 can be produced without noticeable breakup into individual pixels. Simulations based on aircraft data show that in local areas elevation variations of 2 - 3 m are detectable in a mirror stereoscope.

A major advantage of the pushbroom stereo concept is that topographic maps can be constructed directly from the digital image data. Simulations have shown that correlation arrays only a few pixels wide yield elevation information equal to or better than that available by human measurement.

Future development most likely will fall into the area of direct conversion of the data stream into digital terrain models. Correlation with other data sets such as Landsat will require the conversion to the digital terrain format.

Acknowledgement

The author thanks the more than 50 JPL employees as well as representatives of government, industry and academia that supported the Stereosat study. This research was carried out at the Jet Propulsion Laboratory, California Institute of Technology under NAS7-100, sponsored by the National Aeronautics and Space Administration.

REFERENCES

(1] Preliminary Stereosat Mission Description, JPL Report 720-33, 1979.