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Proposed Parameters for Mapsat*

The Automated Mapping Satellite System (Mapsat) would have stereo capability, high resolution, and multispectral linear arrays.

Abstract: *Landsats-1, -2, and -3, although not defined as mapping satellites, are in fact effectively recording the Earth's surface in a form suitable for presentation as small-scale image maps. These spacecraft have demonstrated the effectiveness of Earth sensing, which should now move from the research to the operational phase. Landsat-D is designed to continue the research effort, but NASA, whose charter precludes operations, has not defined an operational system. An operational Landsat has previously been proposed in technical terms, but this concept was limited to the orthographic (two-dimensional) mode demonstrated by Landsats-1, -2, and -3. Mapping involves topography as well as planimetry, and a satellite compatible with the Landsat that also resolves the three-dimensional mode of topography is proposed. Such a satellite requires very high stability and pointing accuracy. The current state-of-the-art permits such a satellite to be built and flown in a mode suitable for automated modeling of the Earth's surface in three- as well as two-dimensional modes. The satellite would be complementary to or could be combined with the operational Landsat previously proposed and it is suggested that it be designated the Automated Mapping Satellite or Mapsat.*

Background

During the past ten years, Earth sensing satellites have demonstrated a potential for revolutionizing the mapping process. An automated digital system, from acquisition and data transmission through processing to final product, now seems feasible. One year ago such a system, based on the use of multispectral linear arrays, was proposed as an operational successor to Landsat, but was limited to the near-vertical (non-stereographic) view (Colvocoresses, 1977).

Two recognized limitations of Landsats-1, -2, and -3 are their relatively coarse resolution and their inability to resolve the third (vertical) dimension. Improved resolution is obviously required as is also the three-dimensional capability. The introduction of the sterographic mode is the only known practical way of resolving the third dimension. Thus, of immediate concern is a satellite system of higher resolution that can acquire stereoscopic as well as multispectral data in a form suitable for various types of precise mapping. This paper proposes the parameters for an automated *mapping satellite* system (Mapsat).

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Concept and Requirements

A satellite mapping system is recognized as being global in its application. In consideration of this global approach, the satellite should provide data complementary with that of prior systems such as Landsats-1, -2, and -3, which by 1982 will have produced coverage of the land and shallow seas for a decade. However, as indicated above, Landsat resolution is not adequate for many defined applications and the requirement for stereo coverage is now well established. This requirement stems from the basic need to map precisely the Earth's topography as well as the expressed need in many disciplines (geology being the foremost) to view the Earth stereoscopically in conjunction with resource surveys and analysis. An operational system must also be cost/effective, which means that the data should be acquired, transmitted, and processed at reasonable cost. The system should, if possible, be capable of mapping the Earth at the widely used 1:50,000 scale in image mode and in both planimetric and topographic form. It should also be multispectral, with at least three bands in the visible and near-infrared portion of the spectrum. In theory, an infinite number of wavebands might be employed but so far only two bands in the visible and one (or two) in the near infrared have demonstrated operational utility. Bands of longer wavelength, extending into the thermal infrared, may also be justified but for various reasons (engineering and time of day) appear to call for a different satellite. Mapsat data should be in a form that can be processed automatically with a minimum of external calibration data. The concept expressed herein is based on global output equivalent to 200 Landsat (185 by 160 km) scenes per day, although stereo and maximum resolution modes may reduce the amount of coverage. Processing by U.S. facilities is estimated at half the daily output, that is, 100 Landsat-sized images per day. The 100 scenes would be processed in primary (bulk) form with geometric and radiometric corrections based on emphemeris and other a priori information. Of the 100 scenes, an estimated 25 to 50 would be precision processed to ground control and enhanced in accordance with the scene response and specified instructions. It may be assumed that the aggregate processing by foreign facilities will be of the same order (100 bulk and 25 to 50 precision processed scenes per day) but the system would be capable of perhaps twice this volume. Durability and reliability are key factors in the system concept, with a ten-year life as the goal.

In addition to these guidelines, a limit on the transmitted data rate is considered essential. This limit is currently set by the reception and processing capacity of the operating (and under-construction) Landsat receiving stations, which is 15 megabits per second (15 Mb/s). The system should be capable of producing, in both digital and analog form, Earth surface information with the following characteristics:

(1) Relative spatial accuracies in the 7 to 25 m error range and absolute accuracies (independent of control) in the 50 to 100 m error range, referred to root-mean-square (RMS) error analysis as determined independently in three (x, y, z) axes of coordinates. In areas where ground control is available, such accuracies will permit mapping at 1:50,000 scale, with contours of 20 to 50 m at U.S. National Map Accuracy Standards. In areas where ground control is not available, similar scale and contour intervals can be used, but the absolute errors will be several times larger, in the 50 to 100 m range.

(2) Multispectral response suitable for analog display at 1:50,000 and smaller scales, which depicts land and shallow sea areas with water penetration up to 30 m. Information should be suitable for presentation as image bases as well as for derivation of specific data for line mapping. The information also must be suited to automated isolation and accurate cartographic portrayal of specific topics (themes) such as open water, vegetation, snow and ice, relief (natural or derived), and cleared (panchromatically highly reflective) areas.

The system should also be capable of producing derived digital tape and photographic images to support applications other than mapping and charting, such as determination of key terrain points and derivation of statistical data concerning land cover within a given area at a specified time (season). However, derivative products will, when necessary, carry geodetic references that provide for geometric accuracies as previously stated.

To achieve geodetic accuracy of 7 to 25 m, external calibration data (ground control) must be used. Horizontal control may be assumed to be spaced at no more than 1,000 km along-track and close enough cross-track (about 100 km) so that any orbit will pass over a control point every 1,000 km. Vertical control must be spaced more closely, but ocean and lake surfaces of known elevation may be used for vertical control.

In areas where independent mapping is done without control, errors will increase to the indicated 50 to 100 m range.

Stereocoverage is a more-or-less one time requirement, but multispectral data must be obtained continuously and repetitively in order to map significant temporal conditions. More than one satellite may be needed to increase the frequency of multispectral coverage but, if so, the second satellite may be entirely multispectral and without the stereo capability as previously proposed (Colvocoresses, 1977). This paper, however, considers only the dual-capability satellite, which combines stereoscopic and multispectral data acquisition. Figures 1 and 2 illustrate the basic sensor mode and configuration.

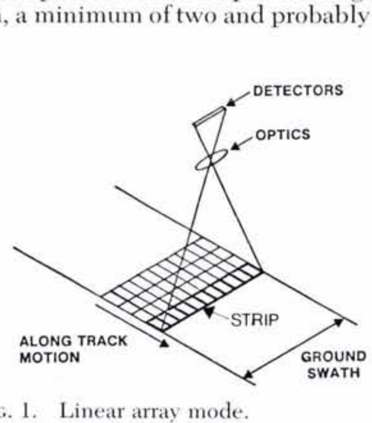

FIG. 1. Linear array mode.

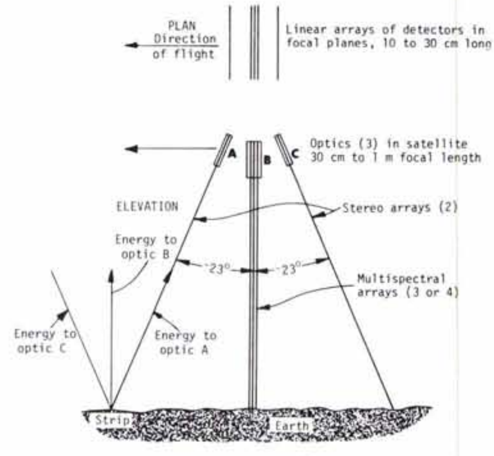

FIG. 2. Mapsat sensor configuration (not to scale). Note: Optics A, B, and C are a rigid part of the satellite; optic B senses the same strip 60 seconds after A; optic C senses the same strip 120 seconds after A; any combination of A, B, and C sensing produces stereo.

SPECIFIC PARAMETERS

(1) *Satellite orbit.* The orbit should be Sun-synchronous, basically circular, and defined in conjunction with the imaging swath width to systematically cover any area of the Earth (with the exception of polar exclusion areas) within a period of not more than 20 days. The orbit of Landsats-1, -2, and -3 is considered near optimum but others should also be examined. Orbits that provide sequential (progressive) coverage daily are preferred to those that skip and thus require longer periods to map areas wider than a single orbital path.

(2) *Sensors.* The sensors must acquire data in digital form with high geometric and radiometric fidelity. A known sensor that provides adequate response without complex moving parts, resulting in higher stability and geometric fidelity, is a linear array with a suitable optical collector, which, according to Landsat-1, -2, and -3 parameters, must have a field-of-view of nearly 12 degrees.

(3) *Imaging modes.* To provide both monoscopic and stereoscopic viewing of the Earth, a minimum of two and probably three sets of optics are needed. For areas of moderate to steep relief, a base-height ratio of 0.5 is required, whereas for flatter areas a 1.0 base-height ratio is desirable. The near-vertical view is required for planimetry and radiometry.

(4) *Spectral bands.* Information theory and experience with television and color photography indicate that the discrete bands of multispectral data need not be all of the same resolution and that a large increase in information can be obtained with a given data rate by using different levels of resolution. Perhaps 90 percent of the spectral differences that occur in the visible and near-infrared do appear in some form in the green-red waveband. Therefore, one band covering the upper portion of the visible should be the band of maximum resolution, with the other bands at perhaps 3 to 5 times lower resolution. The 3 to 1 ratio means that a low resolution band contributes only 1/9th as much to the data flow as the high-resolution band, and the 5 to 1 ratio adds only 1/25th per band. As a mimimum a three band system is needed:*

(a) 0.47 to 0.57 μm blue-green — low resolution
(b) 0.57 to 0.70 μm green-red — high resolution
(c) 0.76 to 1.05 μm near-infrarad — low resolution

* A fourth low-resolution band of 0.70 to 0.80 μm is being considered to support geologic, water quality, and other applications.

(5) *Sampling frequency.* Generally, equal resolution in the two prime directions (cross-track and along-track) is desired. Sampling should be frequent enough for the resolution in the along-track direction not to be materially degraded. For resolution elements (pixels) of larger than 15 m, a sampling frequency of once per element dimension is considered adequate.

(6) *Quantization.* The choices are 6 to 8 bits (64 to 256 radiometric levels). This is a key parameter that must be weighed against data transmission rates. Seven or 8 bits are theoretically desirable but their advantages over 6 bits, as used on Landsats-1, -2, and -3, have not as yet been demonstrated since the radiometric signature of most items desired is mixed with a good deal of extraneous spectral noise that tends to defeat the advantages of finer radiometry or quantization. The final choice may depend on the degree to which onboard data compression can be applied.

(7) *Data storage.* For imaging areas outside the range of ground receiving stations and in order to acquire high-resolution or stereo data over a sizable swath width, onboard data storage is required. Data acquisition at rates up to 30 Mb/s is expected, in which case direct transmission at 15 Mb/s and onboard storage at 15 Mb/s would be required. Storage must be of a form that will not appreciably affect spacecraft stability and should be adequate to store the data for a 185-km swath of 16-m pixels (one band) at least 5,000-km long.

(8) *Data transmission.* The transmission rate should be compatible with Landsat receiving stations. At present, 13 stations are operating or are being built, and more are expected. They all can handle 15 Mb/s, which is considered an adequate rate. It is assumed that these stations will receive and process Mapsat data. Transmission antennas must not degrade spacecraft stability and therfore should be fixed, and transmission wavebands must be approved by international regulatory agencies. The system should provide for data transmission to the United States as required. This may be accomplished in one of the following forms:

(a) retransmission of data from the local receiving station to a communications satellite or NASA's *T*racking *D*ata *R*elay *S*atellite *S*ystem (TDRSS),
(b) onboard data storage and transmission direct to a U.S. station, or
(c) delivery of tapes.

(9) *Data compression.* Data compression that involves such techniques as transmitting radiometric changes rather than the signal itself should be considered. However, only techniques that have been fully tested should be employed.

(10) *Power and power supply.* The satellite must be designed for low power consumption. Solar panels will supply the power, and they should remain fixed during image accession.

(11) *Swath width.* Landsats-1, -2, and -3 cover a 185-km swath width, based on orbital path spacing of 163 km at the equator. If possible, this parameter should be retained for continuity. In order to achieve high resolution in the stereo mode, the swath width may be divided into two (or three) sectors, in which partial coverage is acquired on a single pass. The 185-km swath of Landsat is based on 14 percent sidelap of adjacent scenes at the equator. Increases in spacecraft and orbital stability should permit some reduction of the 14 percent overlap, which will reduce the 185 km swath while still retaining nominal scene coverage and adequate sidelap.

(12) *Platform stability.* For automated processing of data, the platform (satellite) must have very high stability. Rotational rates should be programmable to within 10^{-6} degree per second in all three axes. The pitch rate must agree with the angular acceleration of the spacecraft with respect to the local geometric vertical, and the yaw rate must correspond to the change, due to Earth rotation, of the spacecraft velocity vector as projected on the rotating Earth.

(13) *Attitude control and determination.* In addition to very low rotational rates, the spacecraft attitude should be controlled to within about 0.1 degree of the local geometric vertical. Attitude recording, probably through stellar sensors, should be provided continuously to an accuracy of 5 to 10 arc seconds.

(14) *Positional control and determination.* The satellite must be controlled (orbit adjusted) to the extent that it maintains nominal scene coverage. Orbital drift of no more than 10 km is required. Positional determination in all three coordinates must be within 20 to 30 m so that, in conjunction with attitude determination, the stated independent accuracy criterion of 50 to 100 m in x, y, and z can be achieved. Supplementary devices for determining positions that meet this accuracy criterion must be included.

(15) *Resolution.* Mapsat should provide flexibility in mode of operation, including resolution. The system should be capable of imaging both stereoscopically and mono-

scopically at a resolution based on an instantaneous field-of-view (IFOV) of 10 to 30 m (one band). However, on command or by preprogramming, it should also be capable of IFOV integration by which the resolution can be reduced onboard to a multiple of the smallest IFOV. As stated under Item 4 (*Spectral bands*), only one of the multispectral bands is required to be of high resolution.

(16) *Acquisition modes.* Mapsat is conceived as a multipurpose satellite and, thus, must be capable of operating in selectable modes, such as the following:

(a) Panchromatic stereo at maximum resolution of a portion—perhaps half—of the swath width at maximum base height ratio of 1.0.
(b) Panchromatic stereo at reduced resolution of the entire swath width at maximum base height ration of 1.0.
(c) Combined multispectral and stereo at maximum resolution for a portion—perhaps half—of the swath width at a nominal base height ratio of 0.5.
(d) Combined multispectral and stereo at reduced resolution of the entire swath width at a nominal base height ratio of 0.5.
(e) Combined multispectral and stereo at reduced resolution of the portion of the swath—perhaps half—at both the maximum and nominal base height ratios.
(f) Combined multispectral and stereo at reduced resolution of the entire swath width at the nominal base height ratio.
(g) Multispectral mode only at maximum resolution for the entire swath width.

These seven proposed modes involve complex data management problems that must be addressed and evaluated before final system design.

(17) *Systems output.* The system should produce, through automated data processing:

(a) Raw-data digital tapes from which quick-look data can be retransmitted or produced as black-and-white images.
(b) Processed digital tapes calibrated and corrected both radiometrically and geometrically to a defined map projection, such as the Space Oblique Mercator (SOM). These data will be two-dimensional (planimetric).
(c) Panchromatic and multicolor images basically free of geometric distortions and radiometric anomalies.
(d) Tapes that define topography (elevations) as well as planimetry and are suitable for generating images that depict both elevations and planimetry. The tapes can be produced by what is basically unidimensional data processing, since given detectors from two arrays can produce a stream of one-dimensional data which defines

TABLE 1. PROPOSED MAPSAT PARAMETERS

- ORBIT—919 km, 9:30 a.m. imaging time (same as Landsats-1, -2, & -3).
- SENSORS—Linear arrays plus 3 optics; 2 optics, tilted fore and aft ~24°, panchromatic (0.47 to 0.70 μm), high resolution 10 to 30 m pixel 1 optic, vertical with 3 (or 4) *m*ultispectral *l*inear *a*rrays (MLA).

  band 1 0.47 to 0.57 μm, 30 to 90 m pixel
  band 2 0.57 to 0.70 μm, 10 to 30 m pixel
  band 3 0.76 to 1.05 μm, 30 to 90 m pixel*
- STABILITY—Rotational rates within 10^{-6} degrees/second.
- POINTING ACCURACY—Within 0.1 degrees of vertical.
- POINTING DETERMINATION—Within 5 to 10 arc seconds.
- ACQUISITION MODES—Variable as to resolution, B/H ratio, and division (portion) of swath width.
- TRANSMISSION MODES—Fixed antenna, direct to ground and relay to U.S., and/or onboard recording.
- DATA TRANSMISSION RATE—15 Mb/s (same as Landsats-1, -2, & -3).
- DATA PROCESSING—Automated, based on one-dimensional data correlation, ephemeris data, and/or limited ground control.
- PRODUCTS—Multispectral stereoscopic digital data compatible with 1:50,000-scale topographic, planimetric, and thematic mapping. Positional accuracy of 7 to 25 m relative and 50 to 100 m independent of control.

* possibly redefined as two bands (0.70 to 0.80 μm and 0.80 to 1.05 μm).

both elevation differences and planimetry.

SUMMARY

The proposed Mapsat parameters are summarized in Table 1. A conceptual design study would undoubtedly modify some of these parameters.

REFERENCE

Colvocoresses, A. P. 1977. Proposed Parameters for an Operational Landsat, *Photogrammetric Engineering and Remote Sensing*, Vol. 43, pp. 1139-1145.

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2. Ordinarily *two* copies of the manuscript and two sets of illustrations should be submitted where the second set of illustrations need not be prime quality; EXCEPT that *five* copies of papers on Remote Sensing and Photointerpretation are needed, all with prime quality illustrations to facilitate the review process.
3. Each article should include an abstract, which is a *digest* of the article. An abstract should be 100 to 150 words in length.
4. Tables should be designed to fit into a width no more than five inches.
5. Illustrations should not be more than twice the final print size: *glossy* prints of photos should be submitted. Lettering should be neat, and designed for the reduction anticipated. Please include a separate list of captions.
6. Formulas should be expressed as simply as possible, keeping in mind the difficulties and limitations encountered in setting type.

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