MAPSAT COMPARED TO OTHER EARTH-SENSING CONCEPTS*

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ABSTRACT

During 1980 ITEK Corporation in conjunction with TRW conducted a feasibility study of a U.S. Geological Survey (USGS) proposed satellite system known as Mapsat. Mapsat differs from other proposed systems as follows:

- o It does not involve existing constraints such as transmission through the Tracking and Data Relay Satellite System or the 705-km orbital altitude of Landsat D.
- o It retains the orbit and basic transmission system of Landsat 1, 2, and 3.
- o It involves three- as well as two-dimensional mapping with up to three spectral bands.
- o It is designed for simplified (one-dimensional) data processing, long life, and overall cost effectiveness.

The ITEK study has established feasibility, so it is now appropriate to compare Mapsat with other candidates for an operational Earth-sensing mission. The task of defining the operational system rests with the National Oceanic and Atmospheric Administration (NOAA) of the Department of Commerce. However, the USGS as a major user agency has a large stake in any such system. Moreover, many Earth resource agencies throughout the world in the fields of geology, hydrology, and mapping look to the USGS as the key U.S. Government organization to represent their professional interests. Thus the USGS proposes Mapsat as an operational Earth-sensing system.

BACKGROUND

On September 21, 1966, Secretary of the Interior Stewart Udall announced the creation of the Earth Resources Observation Systems program to study the Earth, its natural resources and environment from space. Secretary Udall and USGS Director William Pecora proposed an appropriate satellite system and NASA responded by building, launching, and operating the Landsat series.

Since 1966, the USGS through its EROS program has played a key role in the development and utilization of Earth-sensing systems. Moreover, the EROS Data Center of the USGS is the U.S. sales facility that distributes Landsat data on a global basis. The USGS has actively encouraged the Earth-sensing concept with the expectation of the evolution of an operational system. However, no government agency, until recently, has had the authority to define an Earth-sensing system other than for experimental purposes, and this is one reason why no operational system has evolved.

On November 16, 1979, Presidential Directive NSC-54 was issued. It assigned the management responsibility for civil operational land remote sen-

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sing activities to NOAA of the Department of Commerce. While the governmental responsibility for operational systems has been assigned to NOAA, the USGS and other concerned agencies should make vital contributions to define such operational systems, which according to NSC-54 should be based on Landsat technology.

For nearly 9 years Landsat satellites (originally designated ERTS) have been imaging the Earth from space. The Landsat program is well documented (1,2,3) and has established remote sensing from space as a recognized discipline throughout the world. The latest Landsat (Landsat-3) carries return beam vidicon (RBV) cameras of 30-m resolution* as compared to 80+ m for Landsat-1 and -2; even so, Landsat is a relatively low-resolution system and is thus limited with respect to making detailed studies of the Earth. Moreover, Landsat lacks the stereoscopic mode essential to the delineation of elevations of the Earth's surface. The acceptance and use of Landsat products clearly indicates that there is a need for a truly operational Earth-sensing system, and that this need is considered to be global and not restricted to any one country or group of countries. Whether or not the United States develops a truly operational system depends on many unanswered questions. It should be noted that several foreign governments (France, Japan, Germany, India) and agencies (European Space Agency, United Nations) are considering the development of an operational Earth-sensing satellite system or systems. From all indications some such system will evolve during the 1980's. Because of the high cost involved, it is hoped that such systems will be international in nature--perhaps similar organizationally to the global communications systems--rather than each interested country developing its own system.

Landsat D (4,5) is scheduled for launch during 1982, but because of its limitations (very low production capabilities for Thematic Mapper data, and no stereo capability) the USGS does not view Landsat D as an operational system or even as an operational prototype.

On December 3, 1980 NASA issued a request for proposal (RFP) for an MLA (multispectral linear array) Instrument Definition Study (6). The MLA described is "to potentially support an Operational Land Observation System (OLOS)." Awards, not to exceed $450,000 each, are called for by the RFP. Four successful proposers (Ball Bros., Honeywell, Eastman, and Hughes) were announced on April 7, 1981, and the study is expected to be of 6-months duration after awards are made. This study addresses linear array technology, but does not include the geometric constraints of a mapping satellite that to many, including the USGS, should be an integral part of an operational system. The MLA study calls for two "short-wave" infrared bands (1.55 to 1.75 μm and 2.08 to 2.35 μm). However, the cost and complexity of recording such bands with solid-state linear arrays plus their limited use to date, make them unlikely candidates for flying on any operational system during the 1980's.

SYSTEMS COMPARISONS

There are two primary modes for imaging the Earth--by aircraft in the atmosphere and by satellites in space. For single-country coverage the aircraft mode probably holds the economic edge, but for global coverage satellites have a definite advantage. Many of today's problems related to energy, natural

*The term resolution as used herein refers to the effective resolution element which is defined as the instantaneous field-of-view of the sensor element coupled with the estimated spread function of the sensing and primary processing system.

and cultural resources, and the quality of environment are clearly of a global nature. Thus if man is to properly understand and monitor both the natural and manmade occurrences on this planet he must utilize a space system.

The options related to space sensor systems fall into three groups, namely film cameras, electro-optical systems, and microwave radars. Film cameras represent a proven technology, especially for topographic mapping, but they are not suited for the multispectral continuous monitoring of the Earth so successfully demonstrated by Landsat. The third group, microwave radars, are needed where illumination limitations or atmospheric opacity preclude the use of optical sensors that use the Sun as their imaging energy source. This leaves electro-optical sensors, which again subdivide into three groups; vidicons (TV), opto-mechanical scanners, and solid-state detector arrays.

Vidicons are represented by the RBV's of Landsat 1, 2, and 3 and the opto-mechanical scanners by the MSS of Landsat 1, 2, and 3; the Thematic Mapper (TM) planned for Landsat D and/or D'; and the conical scanner flown on Skylab as experiment S192. The vidicons are relatively poor radiometers and, therefore, not well suited for multispectral applications. The opto-mechanical scanners of Landsat utilize oscillating parts which create geometric problems and are subject to mechanical failure. The conical scanner of Skylab moves in a simple uniform rotation, but the processing of conical data, as opposed to the linear data of the MSS and TM, poses problems which have weighed against this type of imaging system. However, it is interesting to note that a new type of laser scanner, designed for the mapping of shallow sea areas from aircraft uses the same conical scanning system (7).

The sensors remaining to be considered are the solid-state detector arrays (8). They can be fabricated in either a two- or one-dimensional configuration. The two-dimensional form can, in theory, produce an instanteous image similar to that of a frame film camera, except that each element is discrete and normally quantified in digital form. However, a continuous imaging system which is devoid of the discontinuities created by framing cameras is highly desirable, and such continuous imaging can best be obtained by one-dimensional (linear) array sensors.

The advantage of solid-state linear arrays for a space sensor system are manifold. A few of these include: light weight, low power use, long sensor life, no moving parts, high geometric fidelity, compatibility with stereo system and one-dimensional processing of data. These advantages all add up to high cost effectiveness, an essential element in the consideration of any operational system.

Two of the advantages of linear arrays warrant amplification--namely stereo compatibility and one-dimensional processing. Landsat's inability to provide adequate stereo coverage and thus provide for the delineation of height is a serious deficiency. Elevation data are required for an ever-increasing list of applications, and for most of these applications, elevation data in <u>digital form</u> are required. Digital elevation data (digital terrain data, digital elevation models) geometrically define the Earth's surface in three dimensions and in a form from which the following types of products can be computer generated:

o topographic contours and topographic derivatives such as slope maps, profiles, drainage areas, and elevations of key points or areas.

- o relief depiction under any desired condition of illumination, vertical exaggeration, or perspective. This has obvious application to those geoscientists concerned with the size, shape, and distribution of Earth surface features. This relief depiction capability also permits terrain data to be stored on-board an aircraft or other platform where it can be correlated with "live" radar response and thus used in the automation of navigational systems.

- o terrain aspect correction algorithms to normalize radiometric responses distorted by slopes and thus aid in the automated classification of the Earth's surface and its cover.

- o cartographic products composed of or derived from two or more data sets of which one is elevation data.

Equal to the stereo capability in importance, is one-dimensional data processing. Existing systems involve two-dimensional storage and analysis of data. A Landsat image for example (one band) involves about 10,000,000 picture elements (pixels), and a thematic mapper image (one band), nearly 100,000,000 pixels. Data processing has been the Achilles' heel of all remote sensing systems, including photographic systems from which data compilation, particularly in the stereo mode, is both slow and costly. With linear arrays it is possible to reduce data processing from a two- to one-dimensional problem, and this applies to the stereo as well as the monoscopic mode.

Thus, linear arrays were selected as the logical sensor design for an operational system, but there are two major limitations which must also be considered. The first limitation is detector calibration, since thousands of detectors are involved for each waveband. No two detectors respond identically and thus the radiometric calibration of a linear array is a sizeable task. If one demands very fine radiometric precision to a fraction of a percent, linear arrays are not the answer. However, the sensing of any specific feature or phenomenom on the Earth's surface generally involves "noise" from various sources which add up to a few percent of the signal itself. It is believed that linear arrays can be calibrated to within one percent of expected signals, and this should be adequate for general purpose remote sensing of the Earth.

The second limitation is that available detectors and optics limits waveband response to about 1.05 μm. Longer waves generally require cooled detectors and reflective rather than refractive optics and, moreover, the available energy in the 1 to 5 μm range (short-wave infrared) is quite low. Recording the Earth's response in that range is both costly and technically difficult. It is known that certain vegetation and rock types, under suitable conditions, will give unique signatures within this range but the overall utility of such sensing has yet to be established.

MAPSAT

Mapsat is the result of a USGS effort to define an operational Earth-sensing system. It is based on Landsat technology, and includes the following concepts:

- o Global coverage on a continuous basis.

- o Open data dissemination in reasonable time and at reasonable cost.

- o Variable resolution, swath-width, stereoscopic and multispectral capabilities.
- o Capability of 1:50,000-scale image mapping with a 20-m contour interval.
- o Continuity with respect to Landsat-1, -2, and -3 including the same basic data transmission and reception system.
- o Cost effectiveness including one-dimensional data processing.

Details relative to Mapsat are covered in other papers (8,9,10) but a few points warrant elaboration.

o Mapping geometry. The name Mapsat implies a mapping system, but this does not mean its primary function is to serve the mapmaker. Disciplines such as geology, hydrology, agriculture, geography, and engineering, to name a few, require multispectral data in accurate mappable form. Raymond Dideriksen (written commun., 1976) of the U.S. Soil Conservation Service has stated, "Until the geometric accuracy and resolution are greatly improved we cannot consider Landsat or LFO (Landsat Follow-On) to be competitive cartographic tools when compared with either high-altitude photography or cameras such as those that were demonstrated in Skylab." Here a Department of Agriculture spokesman is calling for a space system of higher geometric fidelity and resolution, and it is hard to conceive of any other serious user to whom geometry is not important. Geometric precision, which is essential to the cartographer, is also the key to an operational Earth-sensing system, and thus the name "Mapsat" has been applied. The products envisaged from Mapsat are by no means limited to conventional planimetric and topographic maps but include thematic displays and other products which can be derived from digital elevation data.

The high geometric fidelity of Mapsat is achieved by defining a spacecraft and sensor system having virtually no moving parts and very precise position and attitude determination. The sensor system is based on rigid solid-state linear arrays rather than mechanical scanners such as used on Landsat. Moreover, the antennas are defined to remain rigid as are the solar panels during periods of data acquisition.

o Resolution and data transmission. Mapsat is designed to use up to three spectral bands at various resolutions and swath widths. Areas requiring high resolution may be so covered with an effective resolution element as small as 10 m. Fortunately areas requiring such relatively high resolution are generally of limited extent. The selection of the spectral band and stereo combinations would also depend on the type of area to be covered. However, a limitation on the data transmission rate is considered essential. By using on-board data compression techniques and data storage, and minor modifications to to the existing Landsat receiving stations to increase their capacity, the existing S-band Landsat transmission system should be adequate. However, a single centrally located receiving station, such as near Sioux Falls, S. Dak., would reduce the number of data tranmissions and thus improve the efficiency of the system for coverage of the conterminous United States.

o Spectral bands. The Landsat multispectral scanner (MSS) uses four basic spectral bands. A fifth thermal band was added on Landsat-3 but failed soon after launch. Of the four MSS bands, two are in the near infrared and are largely redundant. In order to optimize data acquisition against demonstrated practical use, the two near-infrared bands have been consolidated into one for Mapsat. The three bands selected are a blue-green (0.47 to 0.57 μm), a green-red (0.57 to 0.70 μm) and a near-infrared (0.76 to 1.05 μm) band. While the importance of a thermal band is recognized, it is considered suitable for Mapsat, which records reflected solar energy. The thermal emissions from the Earth's surface can best be measured before dawn and afternoon to separate the Sun's effects. Thus a sun synchronous satellite other than Mapsat is needed for thermal sensing.

- Stereoscopic capability. As previously stated, the delineation of the Earth's surface in three dimensions is essential for many uses, and Mapsat will be able to do this at two different base-height ratios (0.5 and 1.0) depending on the type of topography involved.

- One-dimensional data processing. One attribute of solid-state linear arrays is that they generate one-dimensional streams of data. For a single-optic vertically oriented sensor system this is easy to see, but for the stereo mode the generation of one-dimensional data is rather difficult to visualize.

  The two dimensions of image acquisition and processing are normally defined as x (direction of forward motion) and y (cross-track direction). For any given Mapsat optic the y component is fixed by the linear array itself and all data sets are generated in what is basically the x direction. In space it is also possible to define two or more sets of linear arrays using two or or more sets of optics looking forward, vertical, and/or aft to create stereo imagery. Moreover, it is feasible (10) to control the spacecraft so that corresponding detectors in two separate optics will track each other as the satellite circles the Earth. This creates epipolar planes which produce one-dimensional (x direction) sets of stereo data. If one assumes that such data will correlate (the same image points identified and located on the two data sets by their radiometric signature) then data processing in stereo as well as monoscopic mode is greatly simplified and can in fact be automated. In so far as is known linear arrays provide the only defined sensor system that can generate the epipolar planes in space.

  For precise mapping ground control is needed, however, with the expected stability and positional accuracy expected of Mapsat, such control need only be and spaced on the order of 1,000 km along any given ground track. The correlated data can be processed by automated means and thus can provide the basis for an automated mapping system. The proper implementation of this concept would greatly reduce data processing time and costs.

On April 3, 1980, the USGS awarded a contract to ITEK Corporation (with TRW as subcontractor) for a feasibility study of the conceptual design for an automated mapping system (Mapsat). ITEK's final report (10) confirmed the feasibility of the Mapsat concept, and clearly indicates that if the U.S. Government decides now to move ahead on Mapsat, such a satellite could be launched in the 1986-88 time frame. Moreover, the system can be built and operated for a 7-year period at an estimated cost of $215,000,000 (1979 dollars). This figure is considered highly reasonable and cost effective when compared to other proposed systems and to the value of the expected products.

CONCLUSIONS

Parameters for Mapsat were first published in April 1979 (9). Since then some modifications have developed as a result of the recent feasibility study. The basic concepts have now been validated and the following conclusions reached:

- The orbital parameters of Landsat 1, 2, and 3 are considered optimum for an Earth-sensing satellite, and the Landsat data tranmission system, with minor modifications, is considered adequate.
- Solid-state linear arrays promise to simplify the problem of multispectral imaging of the Earth from space.
- The epipolar plane condition can be achieved with a properly designed Earth-sensing satellite, and this will permit the delineation of the third dimension of height using linear arrays which produce one-dimensional data flows. Moreover, this condition will permit the automated processing of stereo data into topographic information.
- An Earth-sensing satellite can now be built with virtually no actuated parts and thus achieve a very high stability, expected long life, and increased cost effectiveness as compared to existing and other proposed systems.
- ITEK's report indicates first launch could be as early as 1986 and at a reasonable cost.

In light of these considerations the USGS proposes that the Mapsat concepts be developed into an operational Earth-sensing satellite system.

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