An Operational Earth Mapping and Monitoring Satellite System: A Proposal for Landsat 7*

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ABSTRACT: The American Society for Photogrammetry and Remote Sensing, the U.S. Geological Survey, and the International Society for Photogrammetry and Remote Sensing are pursing similar concepts for an operational Earth mapping and monitoring satellite system. The system proposed will monitor the Earth in a systematic and multispectral mode with a resolution of 10 m or better. In addition, it will acquire stereoscopic coverage in a form that permits the automated compilation of topographic data and digital elevation models. Image maps of 1:50,000 or even 1:24,000 scale are expected products, and the topographic data can support contours of 20-m intervals. The system builds on the successful Landsat and SPOT modes of remote sensing. The Earth's resources and environment will be monitored in a systematic and continual form by such a system which would be relatively inexpensive, because it is based on proven technology.

INTRODUCTION

THE LACK OF A DETAILED TOPOGRAPHIC MODEL of the global land areas is a serious gap in existing data files. Over the past 10 years, various organizations have advocated a satellite system capable of three-dimensional mapping of the Earth's surface. A number of reports (Konecny *et al.*, 1979; Dowman, 1981; National Academy of Sciences, 1982; National Aeronautics and Space Administration, 1988) have recognized and defined the need for such mapping. Not only is topographic information essential to man's use of the land, it is also a needed tool for the scientific study and understanding of our planet. Moreover, a topographic model is needed for proper interpretation of remote sensor data in general.

There are two basic approaches for creating a three-dimensional model of the Earth's surface from space. The conventional approach is to obtain stereoscopic imagery of the surface from which a three-dimensional model can be derived. The second approach is to use a radar or laser altimeter which measures the distance from the satellite to the Earth's surface. When enough data of suitable precision are obtained, a topographic model can be derived. This second approach has been successfully used over oceans, generally flat land, and ice masses such as the polar regions. National Aeronautical and Space Administration has proposed such a concept (NASA, 1988) and it undoubtedly will continue to be applied to the flat areas of the Earth. However, defining detailed topography of land masses by altimeters is not considered feasible. For those areas with extensive topographic detail, the stereoscopic approach is the most practical solution.

Although three-dimensional (topographic) maps have been made of selected areas from existing space systems, no suitable system exists for the efficient topographic mapping of the overall land areas. Space agencies of several countries are now presenting plans for stereoscopic mapping satellites (DFVLR, 1982; Hofmann *et al.*, 1984; Shibasaki, 1987). In addition, the commercial enterprise, EOSAT, has proposed a stereoscopic imaging capability for Landsat 7 (EOSAT, 1989).†

Topographic mapping is expensive and it will probably take a combined effort of the world's concerned governments to produce an effective three-dimensional model of the Earth. The 1992 International Space Year presents a near-term opportunity to initiate action that can fill this serious data gap. Moreover, the world's mapmakers and others have now reached a general agreement about how this should be accomplished (ISPRS, 1984a; 1984b; 1988).

SATELLITE MAPPING FROM EXISTING SYSTEMS

When the first space photographs of the Earth were made public, their value for mapping was apparent. Errors and omissions on existing maps were obvious from hand-held space photographs, and once Landsat was in orbit (1972), the planimetric correction and partial revision of the smaller scale maps and charts of the Earth was begun. The 75-m effective resolution element of the first Landsats generally limited this activity to scales of 1:250,000 and smaller, but as higher resolution systems became operational, partial revision of scales as large as 1:24,000 has become possible. Even when actual revision is not feasible because of resolution limitations, those areas that required revision may be delineated. This is commonly referred to as map inspection. The principal restriction to the use of space data for map revision and inspection has been the data's high cost and the availability of higher resolution data such as aerial photography in some areas.

In addition to the revision and inspection of existing line maps and charts, the space image itself has proved to be a useful product where conventional maps do not exist or where existing maps are inadequate. Image mapping with space data is still looked upon as experimental, but this method of mapping is expanding in spite of high data costs. Today, Landsat has been joined by other systems such as the French SPOT, the Russian camera systems, Indian IRS-1, and Japanese MOS-1, all of which can provide coverage on a near-global basis. However, it should be noted that such mapping activities apply principally to the two-dimensional planimetric mode. Film systems, such as the Large Format and Metric Cameras flown on the U.S. Shuttle, have also demonstrated a mapping capability, but their coverage is quite limited and there are no plans for further flights of these cameras.

EVALUATION OF A THREE-DIMENSIONAL SATELLITE SYSTEM

As soon as space imagery of the Earth became available, it was obvious to mapmakers that such systems had the potential for three-dimensional map compilation as well as image mapping, map revision, and map inspection. Stereoscopic images from a variety of space systems, such as the Large Format Camera, have been used experimentally to make three-dimensional maps.

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†Any use of trade, product, or firm names in this publication is for descriptive purposes only and does not imply endorsement by the U.S. Government.

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SPOT, in particular, can record stereoscopic data with adequate base-to-height ratios, but the side-looking configuration of the stereoscopic data make it difficult to acquire and to process. None of these systems are being applied for cost-effective, comprehensive, three-dimensional mapping of extensive areas.

In 1980, the U.S. Geological Survey entered into a contract with private industry to examine the feasibility of an Automated Mapping Satellite System (MAPSAT) (ITEK, 1981). The concept features the use of linear arrays of detectors with separate optics looking forward, vertical, and aft along the orbital path. The design calls for precise satellite attitude control so that analogous detectors of the respective linear arrays follow each other along the Earth's surface. This concept eliminates *y* parallax, which is the bane of conventional stereoscopy, and results in the stereo data being acquired directly in epipolar planes. The epipolar acquistion greatly simplifies the stereocompilation process and permits at least partial automation of the process through autocorrelation of the stereo data. The MAPSAT concept has been patented (U.S. Patent Office, 1982) and presented to various mapping agencies for consideration (Figure 1). In 1984, the concept was documented by a working group of the International Society for Photogrammetry and Remote Sensing (ISPRS, 1984a), where the MAPSAT concept was renamed the Orbital Mapping System. This committee was made up of professional representatives from six nations and four international organizations (United Nations, World Bank, Inter-American Development Bank, and Pan American Institute of Geography and History). Their report was submitted to and approved by the XV Congress of ISPRS in Rio de Janeiro, Brazil. A resolution (ISPRS, 1984b), recommending consideration of such a system for the orderly and cost-effective mapping and monitoring of the Earth, was forwarded to appropriate space agencies and their respective governments. In 1988, the XVI Congress of the ISPRS, meeting in Kyoto, Japan, unanimously endorsed this resolution of the Rio congress and recommended the formation of an international working group to pursue implementation of the system (ISPRS, 1988). At both the Rio and Kyoto congresses, mapmakers from over 50 countries participated. Thus, it may be assumed that the international mapping community supports the proposed system. In fact, both the Japanese and the French are now defining stereomapping satellites with characteristics similar to those proposed. Within the United States, there appears to be a consensus developing that the next Landsat to be defined (Landsat 7) should include a stereomapping capability. The following proposals and studies illustrate this trend:

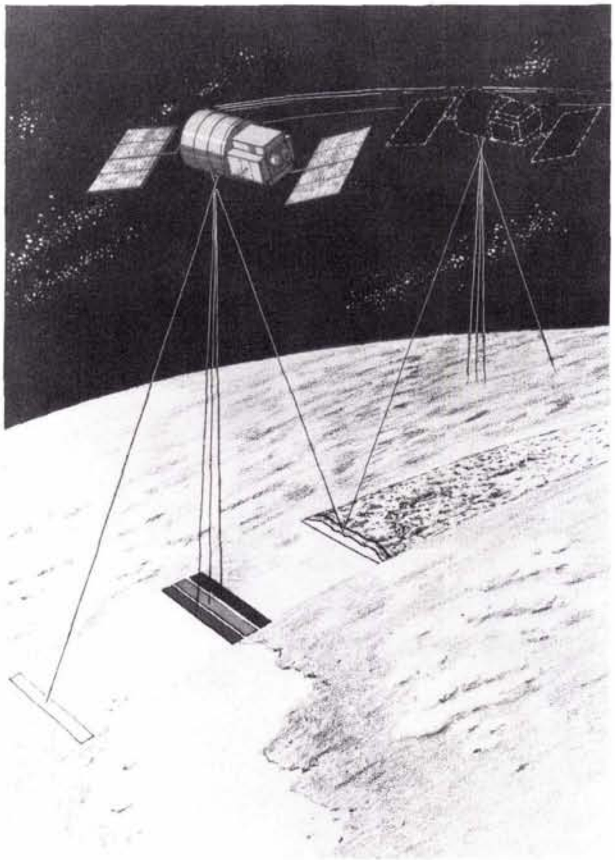

FIG. 1. Proposed Mapping Satellite. Records date from the forward, vertical, and aft looking sensor. Any two of the sensors can record data in stereographic mode. Multispectral acquisition is basically from the vertical sensor. Stereographic coverage is normally limited to a single spectral band.

- A proposal for Landsat 7 by the U.S. Geological Survey (USGS, 1988), endorsed by the U.S. Department of the Interior and transmitted to the U.S. Department of Commerce.
- A similar system proposed by the American Society for Photogrammetry and Remote Sensing during 1988, also forwarded to the Department of Commerce.
- A recent proposal by EOSAT for Landsat 7 (EOSAT, 1989).
- A study for the U.S. Department of Commerce (TASC, 1988) that lists five out of seven market segments for remote sensing data that require stereoscopic coverage and includes stereo in all four of their sensor options.

In addition, there have been numerous recent technical papers supporting the mapping concept and calling for a satellite that produces data for a digital three-dimensional model of the Earth's surface (Light, 1989).

SUGGESTED SYSTEM PARAMETERS

Nearly all groups of potential users of the data from a mapping satellite have their own specific requirements. However, there does appear to be a converging compromise between what is wanted and what is feasible. The following system parameters are deliberately vague but include most of the suggested requirements. They are within the state of the art, are cost-effective, and hopefully conform to economic and political realities.

- *Orbit* - 918-km altitude preferred, lower altitude (to 581 km) acceptable. Circular, Sun synchronous, daily contiguous-swath coverage, descending node crossing 9:00 to 9:45 A.M. local time.
- *Swath width* - 180-km preferred, adjustable to smaller swaths (to 62 km) for high-resolution stereoscopic or multispectral coverage.
- *Sensors* - Three multispectral sets of linear arrays. Refractive optics looking forward, aft, and vertical. Three or four spectral bands selected from the visible and near-infrared that do not require cryogenic cooling of detectors. Recording at 256 gray levels (8 bits). Nondestructive, on board data compression to no more than 32 or 64 gray levels (5 or 6 bits).
- *Spatial resolution* - 10-m pixels capable of on-board aggregation to lower (coarser) resolution. Use of stereo and the offset of spectral band footprints will improve effective resolution beyond the 10 m indicated by the pixel size.
- *Attitude control and determination* - Control within 0.1°, basically to hold satellite vertically along groundtrack but capable of offtrack viewing when required. Spacecraft stability in the order of 10^{-6} degrees per second. Attitude determination to within 5 arc seconds based on stellar sensing.
- *Spacecraft position* - Provided by Global Positioning System or equivalent to within 3 to 5 m in the three basic coordinates.
- *Data transmission* - 50 to 100 Mb/s, at 32 or 64 gray levels (5 or 6 bits), X band through fixed omnidirectional antenna to the network of existing ground stations. On-board data storage on tape recorders or equivalent.

CONCLUSIONS

Three-dimensional mapping of the Earth's surface from space is a large and expensive project, but there is little question that this project is highly justified. It can be accomplished by a single dedicated satellite properly designed and flown to meet the basic global needs for a digital model of the multispectral reflectance and topography of the Earth's surface. The parameters indicated will result in data suitable for 1:50,000-scale image mapping with 20-m contours. Such a project will involve approximately 10 years of effort and perhaps the equivalent of 1 billion of U.S. dollars. Because the Earth is now being looked at as an entity, it is only logical to map it as an entity with a uniform model. While such a satellite is in operation, the Earth surface will also be monitored in multispectral mode and with a resolution that surpasses the civil electro-optical systems available today. Surely the time has come to apply space technology to one of the truly useful tasks that space offers – for the benefit of all mankind.

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BOOK REVIEW

Radar Remote Sensing, A Training Manual by Dirk Werle. Dendron Resource Surveys Ltd., 8809 Lady Ellen Place, Suite 206, Ottawa, Ontario, K1Z 5L9. 193 p. + v. glossary, 75 35-mm slides, 74 figures, 6 exercises with 12 figures, vinyl three-ring binder, 1988, $380.00 CAN ($327.00 USA) in Canada and United States, $410 CAN ($347 USA) overseas. Also available in French. Text and figures available on 5.25 inch disks for IBM-compatiable PCs.

HAS YOUR CHAIR recently approached you about adding a course in radar remote sensing? Has your boss detailed you to compile a report on applications of radar in earth resources? Are you looking for a comprehensive source of radar imagery for your lectures as well as effective laboratory exercises? If you are still searching, making phone calls, or planning to have all of the radar plates in the *Manual of Remote Sensing* photographed – STOP! There is a better, more complete solution waiting for you in Canada.

In preparation for the Canadian RADARSAT mission and companion activities in the United States (SIR-C,EOS), Europe (ERS-1), and Japan (ERS-1), the Canada Centre for Remote Sensing contracted with Dendron Resource Surveys Ltd. to undertake the compilation of a radar remote sensing training manual that could be supplied to post-secondary level educators to assist training scientists to exploit this burgeoning new source of terrestrial information. Dendron further subcontracted Dirke Werle of AERDE Environmental Research in Halifax, Nova Scotia to author the manual. Published in 1988, the manual presents a solid, contemporary survey of aerial and spaceborne radar technology and its applications in terrestrial environmental and resource research.

No doubt the first question most potential customers for this volume have is, "Does it make sense to pay over three hundred dollars for a government training manual published in a three-ring binder?" In this particular instance, the answer is yes! I am sure many of you have had the experience of purchasing slide series and laboratory manuals that consisted of poor quality