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The Processing and Use of Data from Earth Observation Satellites [and Discussion]

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The processing and use of data from Earth observation satellites

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Most systems reliant on advanced technology present a familiar dilemma: the system designer does not know what the customer wants, while the customer does not understand the technology well enough to know what is possible. Although Earth observation satellite systems ought ideally to be designed for all customer needs, this is impossible for several reasons. Not least of these is the difficulty of identifying at the outset all, or even most, of the possible customers.

This circumstance makes the creation of Earth observation systems somewhat speculative and imposes particular constraints on the subsystems for processing and use of the data. This paper discusses the technical and institutional aspects of processing and dissemination of data from remote-sensing satellites for the benefit of the user.

Introduction

The first governmental step towards the industrialization of Earth observation by satellite was taken in 1977, when the Department of Trade and Industry financed the setting up of a centre of excellence in space remote-sensing technology at the Royal Aircraft Establishment. The National Remote Sensing Centre, which is closely associated with the Department of Trade and Industry programme, has been in operation at Farnborough since 1980. In this paper the theme of the meeting is discussed in the light of experience gained from participation in this work.

At the beginning of 1977 there was some research into applications of remotely sensed data going on in universities and elsewhere; a few firms were already applying the data and offering added value services. It was therefore decided that the main thrust of the R.A.E. work should be towards acquiring, processing and disseminating Earth observation data from spacecraft and extension of the technique towards new applications and new users.

It is a truism that the introduction of advanced technology into practical applications is fraught with difficulty. Although reluctance to accept novel systems is usually (and often correctly) ascribed to conservatism, there is in fact a very real dilemma. The system designer is likely to be motivated by 'technology push' and the desire to produce a technically elegant solution. The dilemma arises from the difficulty of defining the problem. The customers may not know what is technologically possible; indeed, most do not know that they are potential customers. Lack of communication between designer and user has in many fields led to the creation of a number of clever and expensive white elephants.

In Earth observation from space this dilemma is particularly acute. The technology is both advanced and expensive: gestation of a new system is protracted; and the range of potential users is large in number, in diversity and in the extent of their technical understanding. Although the design of Earth observation systems is usually preceded by attempts to identify, and to define, most of the possible applications, past remote-sensing satellite missions have invariably led to a number of unforeseen applications. Clearly, there must be many potential applications of existing systems that have yet to be identified, and of course the advances in sensor and supporting technologies will create still more.

This circumstance makes the creation of Earth observation systems somewhat speculative and imposes particular constraints on the subsystems concerned with the processing and use of the data. These constraints affect both the technology to be employed and the institutional structure for acquisition, processing and dissemination.

Data acquisition

The high investment cost of space-based Earth observation is primarily justified by global coverage and hence the potential recovery of those costs from a very large number of users. The inevitable corollary of this is that enormous quantities of data are generated; the output of existing imaging sensors is of the order of 10^8 bit s^{-1} or, if operated continuously, almost 10^{13} bit d^{-1}. Of course, the volume can be reduced by the adoption of sampling strategies and the use of so-called smart sensors or systems that reject unwanted data. In the present ill defined state of the market, the tendency has been to capture all the data that might eventually be useful, and I predict that techniques that irreversibly restrict geographical or temporal coverage will remain unpopular for some time to come. The implications of this, together with improvements in sensor performance, are that data throughput will increase by an order of magnitude by the early 1990s.

The large size of the data sets, and the rate at which they are generated, tend to determine the design of the ground segments of Earth observation systems. High bit-rates occupy large bandwidths in data transmission from spacecraft to ground and from ground station to user. Data processing often involves the manipulation of large matrices, and the configuration of the facilities used is usually dominated by input, output and storage requirements. The requirement for archives, both in data storage technology and in system architecture, is extremely demanding. The other major influence on the ground segment is the timescale in which the processed data are required; the nearer to real time the requirement and the larger the area to be covered, the more expensive the operations are likely to be. If these constraints are related to the existing state of the art the following scene emerges.

Data recorders on-board unmanned satellites have capacity for only a very small part of the potential coverage per orbit of high resolution imaging sensors. The output of such instruments must either be transmitted to a network of ground receiving stations or must be relayed by satellites in higher orbit to one or two ground stations. The N.A.S.A. Tracking and Data Relay Satellite System will use two satellites in geostationary orbit to transmit to a single ground station in the U.S.A. to achieve almost global coverage. Although such a relay system is expensive, so is the alternative of a network of direct receiving stations. Because of the large signal bandwidth it is necessary for transmission systems to operate at microwave frequencies. Typically, ground station antenna apertures of 10 to 12 m are needed, and the resulting narrow beamwidth combined with the tracking requirements for low Earth orbit call for high angular rates of antenna motion and sophisticated control systems. Reception, demodulation and demultiplexing pose no particular problems, but data capture (i.e. recording) and real-time processing may well do so. Serial multitrack magnetic tape recorders are available, which can accept data at rates approaching 10^9 bit s^{-1}, but investment and running costs are high. Further, serial records cannot be accessed directly by conventional computers. The use of helical recording techniques may permit the development of computer addressable serial recorders for high bit rates, but progress has been slow.

Data processing

At present, applications of Earth observation that require real-time or near real-time delivery of data (such as meteorology and oceanography) can be satisfied by data from sounders and from imaging sensors of modest spatial resolution. The data handling and processing functions for these can be performed in real time by conventional mini- or micro-computers. However, as the AGRISIPINE experiment made in 1982 demonstrated, there is a range of potential time-dependent applications that can only be satisfied by supplying high resolution processed data within a few hours of acquisition. All-weather day and night sensing by synthetic aperture radars (SARS) will add a further quantum of data processing capacity to the ground segment specification. The current approach to processing of large data sets from imaging sensors is to use one or more of the faster minicomputers, in conjunction with special purpose pipeline or parallel hardware processors for particular operations. These are unable to cope with the throughput in real time and the standard technique is to replay the original serial record at a fraction of the record speed to slow down the operation. Typically, the record: replay ratio is limited to 16:1 or thereabouts; this is insufficient reduction for most SAR processors currently available and a further stage of transcription is necessary for this sensor.

The advent of powerful processors 'on a chip' and equally compact random access memories will permit the development of faster data processing systems in which the architecture is optimized for specialized applications, but which can employ standard computer peripherals and communications interfaces. It will be necessary to ensure that fast processors are not, as at present, constrained by input–output limitations.

The processes performed at the ground station are what is usually termed pre-processing; this consists of the removal of artifacts of the sensing process, corrections by using pre-flight or in-flight calibration data, and location of the data set on the Earth's surface by using prior knowledge of the satellite orbit.

A further phase, usually termed precision processing, consists of radiometric and geometric correction by using *post hoc* information such as refined measurements of the satellite orbit and attitude and ground control points. This work is usually done in specialized centres such as the National Remote Sensing Centre. The output is normally in image form, transformed into the coordinates of a specific map projection, and may be supplied to the user as a computer-compatible digital record or a photographic image.

At present, archives are formed of the data at each of these stages; a primary archive on serial tape at the ground stations and secondary archives of pre- and precision-processed data at National Centres. It may be foreseen that operational remote-sensing systems will adopt a rather different approach. The needs of time-dependent users will be met by on-line processing on-board the satellite or at the ground stations, and precision-processed products will be generated as standard for all other users. All archives will be held in computer-addressable form and the community using remote sensing will continue, with others, to urge the computer industry toward the adoption of cheap high-density recording media such as 'laser discs'. Further development will be needed to produce a better recording system for data capture at the ground stations.

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For experimental missions, and for archiving of meteorological data for research purposes, sampling strategies will have to be evolved to reduce the volume of data to manageable proportions.

Analysis and interpretation

The ultimate customer of operational remote sensing is unlikely to be able to make direct use of an image or tabulated data, and may be satisfied by something as simple as a 'yes or no' answer, a date or a few numbers. The most frequently used technique for transforming images into such information is still visual interpretation. I predict that this method will continue to be used for many years, but that increasingly sophisticated machinery will be deployed to aid the interpreter. In parallel, knowledge-based systems will increasingly be used for operational analysis and interpretation and ultimately the two strands of development will tend to merge. One can envisage an expert system initially 'learning' from a skilled human interpreter and subsequently developing faster and more efficient procedures. In the meantime there is a substantial market for interactive analysis hardware and software ranging from the fast, flexible and expensive to the slow, simple and cheap. The provision of facilities for remote sensing to be used in secondary and even primary education is an essential prerequisite of its industrialization.

There is, of course, a market for those skilled in analysis and interpretation to sell their services to those who are not. It may be, however, that, as for telegraphists and telephone operators, the advance of information technology may eventually reduce the number of jobs in this area.

Dissemination

In pursuing the flow of data processing from ground station to user, the means of data transmission has so far been ignored. Although, during pre-processing, there is a natural tendency for the volume of unique data to be reduced (for example, cloud obscured or poor quality data are discarded), the replication of data sets for a number of users tends to maintain or increase the total volume to be disseminated.

At present, most dissemination is by telephone lines for meteorological data, and by post for computer-compatible tapes of data of high resolution. Both of these methods have their limitations. The SPINE experiment demonstrated that the routine delivery of Landsat data to national centres in the U.K. and Sweden by a 2 Mbit s^{-1} satellite communications link was beneficial to many users in those countries. The AGRISPINE fast delivery experiment was also successful in supporting several time-dependent applications during the agricultural growing season in 1982. This transmission rate has been adopted for the terrestrial Metsatnet communications network, which will be installed in 1984 to transfer environmental data within the U.K. It seems likely that, where time is of the essence, international distribution by satellite, and internal dissemination by wide-band terrestrial networks, will become the norm. The services offered by common carriers will readily accommodate these requirements.

For other users, postal distribution of computer-compatible tapes, floppy and video discs are likely to persist, but increasing use will be made of controlled broadcast via cable networks and of dial-up facilities for small users to gain access to publicly available archives. Such archives will have to be carefully designed to meet the needs of a wide range of future users.

This broad and necessarily superficial review might be summarized by stating that the

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technical problems likely to arise in the industrial exploitation of remote sensing from space are not trivial, but solutions to all of them can be foreseen within current technological developments. That is not, of course, to say that the solutions will necessarily follow precisely the forecasts given in this paper.

Table 1. Order of cost of entry

	£
space segment operator	over 10^8
ground segment operator	over 10^7
digital data analyst and interpreter	10^4–10^6
visual interpreter	under 10^2
teacher	*ca.* 10

Institutional aspects

The institutional problems will be harder to solve. Their scope is illustrated in financial terms in table 1, which indicates the order of cost of entry into the remote sensing business for a range of possible participants. For particular applications, where existing sensors can already offer quantifiable benefits, national, public or private sector ownership of space segments is possible. However, for experimental missions and for operational missions employing advanced sensors, such as multi-spectral radars, it seems likely that international initiatives will be needed.

What is quite certain is that encryption of transmitted data will become standard practice, and that the owners of space segments will thereby exercise some control over ground segments and over the exploitation of the data. This could include manipulation of the market for ground station equipment, withholding commercially valuable data or simply maximizing revenue. It is thus necessary for the U.K. to participate effectively in both space and ground segments if continued availability of data to U.K. industry is to be assured. For the space segment, membership of the appropriate international clubs may perhaps suffice, but in any case a powerful national capability for acquiring, processing, archiving and disseminating data is clearly essential. It should be noted that 'disseminating' to end users is synonymous with 'selling'.

The extent to which these facilities should be publicly or privately owned is outside the scope of this paper, but there are a number of factors to be considered in this context. The first is the relation between the market and the technology, mentioned in my introduction. The rest arise mainly because the investment needed for a comprehensive ground segment is substantial, not only for hardware but also for the research necessary before novel sensors can be fully exploited. On the other hand, many of the potential customers will make only a small contribution to investment and operating costs, while requiring a disproportionate amount of technical advice and support. A national facility has to provide the support if the use of the technique is to grow. The establishment and maintenance of a national global archive also requires substantial investment while generating rather small revenue, at least in the early stages.

There are currently just over 250 active customers of the U.K. National Centre and they are divided almost equally between government, industry and academe. All groups make use of data from the U.K. and overseas, and it would appear that most of the major revenue-earning applications in the industrial sector are overseas. Although these proportions have persisted throughout the existence of the Centre, there are now some indications that, while each group is growing in absolute terms, the industrial customers are becoming relatively more numerous. The Centre, in supporting industrial initiatives, has to maintain strict impartiality and confidentiality when, as often happens, it is concurrently supporting several competitors for the same contract.

The prices currently charged for data and data products, which ultimately are determined by the space segment operator, are non-optimum. They do not provide a realistic return to the operator; they are high enough to deter the academic researcher or teacher, while being so low in the perception of the industrialist that he is inclined to doubt the potential value of the product. This situation will change rapidly as satellite owners seek to recover more of their costs, and the academic community is likely to suffer in consequence. Clearly, steps must be taken to permit research and teaching to continue in this new cost environment. It has been suggested more than once that payment for commercial use of data should be by way of levy on profits achieved from exploitation, but it is difficult to see how this could effectively be regulated on a global scale.

Another issue to be faced is the distribution of ground facilities; the provision of data acquisition stations is likely to be centralized while analysis and interpretation facilities tend to proliferate. This is quite natural but, as has been described above, there are a number of functions interposed between these interface points for which the decision is less clear cut. Moreover, technological development is likely to change the constraints that have given rise to contemporary arrangements.

Whatever the ultimate national infrastructure, and whatever its ownership, it must not inhibit the individual or corporate entrepreneur from exploiting the technique. Further, it must seek to create opportunities for such local initiatives while pursuing international partnerships.

Conclusion

The objective of this paper is to promote discussion. From a particular viewpoint, a number of technical and institutional problems have been identified. Other relevant issues will be perceived by others with different perspectives. The successful industrialization of Earth observation from space will depend on sensitive resolution of these issues and of the often conflicting objectives of their proponents.

Discussion

D. O. Fraser (*British Aerospace p.l.c., Dynamics Group, Space and Communications Division, Bristol, U.K.*). In view of the problems of world coverage for SAR imaging referred to by Sir Peter Anson and the need for coordination between remote-sensing satellites, does Mr Hardy think an international-remote sensing organization, comparable to Intelsat and Inmarsat, may be formed?

D. D. Hardy. That is certainly a possibility, but there is a countervailing tendency (Spot, Landsat) toward national and private sector investment in remote sensing, which may, or may fail to, lead to operational systems. There is also a tendency for the more ambitious and complex pre-operational systems – of which Radarsat is an example – to be organized on a bi- or trilateral basis.

Coordination does not necessarily imply multilateral operating entities and I would point to the work on data format standardization that has already been done by informal international groups.

In the end, one has to balance the inherent inefficiency of multilateral bodies against their political and financial advantages. At present there is no apparent will to create such a body for remote sensing.

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