SATELLITE REMOTE SENSING

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Summary

Remote sensing, using data gathered by Earth-orbiting satellites, provides the opportunity to gather geophysical and environmental information more quickly, cost-effectively, and comprehensively than by using conventional ground-based methods.

The main components of a satellite remote sensing system are indicated and the principal satellite missions of the late twentieth century are described. Applications of remote sensing in meteorology and atmospheric sounding, oceanography, topographic and geological mapping, land use, agriculture, range-land management, and forestry are outlined. One or two features of the analysis and interpretation of satellite-received data are considered. There is a discussion of current and future remote-sensing satellite systems. The tendency is towards producing small more specialised satellite systems designed for specific geophysical or environmental tasks, rather than for general environmental monitoring work. More countries are becoming involved in space technology, including remote sensing.

1. Introduction

Space science and technology have enabled humankind to make observations of the earth from space and to obtain a view of vast areas of the planet of a kind never available before. This has enabled the study of natural resources, human activities, natural disasters, and the monitoring of human-induced environmental changes to be carried out over much larger areas and in far greater detail than can be achieved by conventional ground-based observations. The present-day technology whereby we have the capability to operate remote sensing (Earth-observing) satellites owes its origins to the rocket technology that was developed in World War II. Captured German V-2 and Viking rockets were used for research and development work after the war by the former allies. In the early days, rockets were fitted with instruments and cameras to gather meteorological data and cloud images that were returned to Earth. This led to the idea that artificial satellites could be launched into Earth-circling orbits to gather pictures of cloud systems over large areas, potentially over the whole earth. Indeed the term "remote sensing" appears to have been coined by geographers at the (U.S.) Office of Naval Research in the 1960s to render acceptable to a civilian audience a technology that, after the end of World War II and following the start of the Cold War, had undergone massive development for military "spy-satellite" purposes. The world's first meteorological satellite, the Television and InfraRed Observation Satellite (TIROS-1), was launched on April 1, 1960. This ushered in a new era of meteorological observation and weather forecasting. TIROS-1 demonstrated the ability to acquire images of the cloud cover of the earth over huge areas of the planet. Although this was an experimental satellite, the early results were welcomed by meteorologists, who used them to supplement conventional observations. The success of this first spacecraft led to the evolution of a series of weather satellites that now routinely monitor the earth's atmosphere, land masses, and oceans **(see Section 4.1. Meteorological Remote Sensing Satellites)**.

The first artificial satellite, Sputnik, was launched in 1957. The launch of the first meteorological satellite, TIROS-1, in 1960 was followed by the U.S. (and Soviet) military space programs and manned space programs of the 1960s (Mercury, Gemini, Apollo). Meteorology is concerned with the study of the atmosphere and after the initial success of the early meteorological satellites other systems were developed for studying the land and the oceans. The first Earth-observing satellite for land-based applications was Landsat-1, which was launched in 1972 **(see Section 4.2. Landsat)**; since then many more Earth-observing satellites have been put into orbit, with a surprisingly high success rate. The early successes in the land studies area were both by the Landsat series of spacecraft developed and operated by the U.S. and by the SPOT **(**Système Pour l'Observation de la Terre) series of spacecraft developed and operated by the French Centre National d'Etudes Spatiales (CNES).

We note that there is a convenient division of satellite remote sensing systems into operational systems and experimental systems. An operational system is one to which there is an ongoing commitment to the continuation of the system for the foreseeable future. An experimental system is a satellite or a set of satellites launched for a particular investigation and where there is no firm commitment to the continued operation of the system. Meteorology was the first field of environmental activity to benefit from satellite technology and it remains the most successful to date. There is now a set of operational meteorological satellites that can be assumed to be maintained in space for the foreseeable future. While not commercial, this system is financed by public bodies, namely the state meteorological services of the countries of the world, and the commitment of these bodies ensures the continuation of the system for the future. Meteorology provides, undoubtedly, the most successful application of remote sensing satellite-derived data, in the sense that the data are used operationally by national weather services around the world. Other systems designed primarily for the study of the land surface have evolved or are in the process of evolving into operational systems. Yet other systems were only ever intended as one-off missions with no intention whatsoever of leading to an operational system.

The whole process of designing, building, and launching a satellite-flown remote sensing system is a very lengthy and costly process. Therefore, in the early days this activity was confined to the United States of America and the former Soviet Union. Subsequently, CNES developed the SPOT system and the Indian Space Research Organisation (ISRO) developed its Indian remote sensing satellites (IRS) system. More recently, a number of countries, including Japan, India, the People's Republic of China, Taiwan, Brazil, and Argentina, have chosen to become involved in the space hardware side of remote sensing by developing satellite-flown remote sensing systems, while in Europe a large number of nations have come together to form the European Space Agency (ESA) for the same purpose.

There is no doubt that the main driving force behind the enormously costly development of space technology has been the military, where cost is not usually a problem. However, the expensive development of the technology has been followed by a transfer to the civilian or commercial sector. The biggest success story, in commercial terms, of satellite technology has undoubtedly been in the field of communications satellites and in global positioning systems (GPS). This has moved on from the development stage of having to be subsidised by government funds to the design, building, launching, and operation of communications satellites being commercially successful and being conducted throughout the whole world. It has not been so, until very recently, with remote sensing for environmental monitoring from satellites; this comes in a completely different category. Satellite remote sensing needs, and will continue to need for quite some time, government support for national projects or international collaborative projects. One can find considerable discussion in the literature of commercial applications of remote sensing, but until recently people were just talking about it.

Traditionally, satellite remote sensing systems have been used for global, regional, and national programs to support government activities. Now, however, with the relaxation on restrictions for ownership and operation of Earth-observing satellites, unprecedented competition has been stimulated among large aerospace companies to create new geospatial products and services aimed at markets never before envisaged, such as news gathering, farming, shipping, and conveyancing as well as the traditional mapping and science community. Commercialisation, in the sense of designing, building, launching, and operating a remote-sensing satellite for commercial purposes, without subsidies from public funding, is now beginning to occur. At present, several commercial high spatial resolution systems, with resolutions of the order of 3–10 m for multispectral images and resolutions in the range of 1–5 m for panchromatic images, are in prospect; after several failures, the first of these to be launched was IKONOS in 1999 **(see Section 4.9. Other Systems)**.

Although this article is concerned with satellite remote sensing, one must make some mention of aircraft. There is a whole field of Earth observation that is involved with using aircraft rather than spacecraft for carrying remote sensing instruments. Extensive use had been made of air photos for many years before satellite remote sensing systems were developed. These air photos are extensively used in mapping and in studying natural resources, in archaeology, etc. Cameras flown on spacecraft produce images of the surface of the earth that are similar to those obtained from aircraft; however, because the satellites fly at a much greater height above the surface of the earth than the aircraft do, the area of ground included in an individual satellite photograph is much larger than that included in an air photo. Satellites and aircraft used as remote sensing platforms are in many ways complementary. The types of instruments that are flown on satellites and on aircraft are similar. For scanners flown on satellites, although the mechanism of image formation is quite different from that of a photograph, the scale of the image from a Landsat, SPOT, or IRS scanner is similar to that of a photograph from a camera flown on a satellite.

There may be advantages, for some applications, in using an airborne system rather than a satellite-flown system. For instance, if one is working in a coastal region and studying the natural circulation of the water or the dispersion of a pollutant one needs high spatial resolution imagery of a rather small area and a rapid sequence of many images over one tidal cycle. An aircraft is very suitable in this situation and a satellite is not. On the other hand, if one is dealing with larger areas and a situation that is not changing rapidly then a satellite is likely to be far more suitable than an aircraft. Another aspect is that if an instrument is at the development stage it will be flown in an aircraft for testing purposes.

2. The Components of a Satellite Remote Sensing System

Some images of the surface of the earth have been obtained from manned spacecraft including space shuttle flights since 1981, some from earlier programs and more recently the Russian space station, MIR. Photographs have been taken with cameras held by astronauts or cosmonauts (i.e. Soviet astronauts) who have received some training in appropriate aspects of basic Earth science. Crews are partly guided from the ground and have attempted to obtain photographs of terrestrial, meteorological, and oceanic phenomena. Approximately 360 000 photographs cover a period of 36 years; one example is shown in Figure 1. However, the vast majority of the data used in satellite remote sensing are from instruments flown on unmanned spacecraft. The principal components of an unmanned satellite remote sensing system include:

- The rocket, or launcher, which is required to transport the satellite from the ground into its orbit
- The spacecraft frame or “bus” on which the various components of the spacecraft are mounted
- The solar panels to provide the electrical energy to power the spacecraft
- The data-gathering instruments
- The on-board systems for the control of the spacecraft and the transmission of the data back to ground
- The ground-based mission control centre for the control of the spacecraft and its instruments
- Ground-based systems for the reception of the data from the spacecraft, the archiving and distribution system for the data received from the spacecraft
- The human and machine systems for the analysis and interpretation of the data

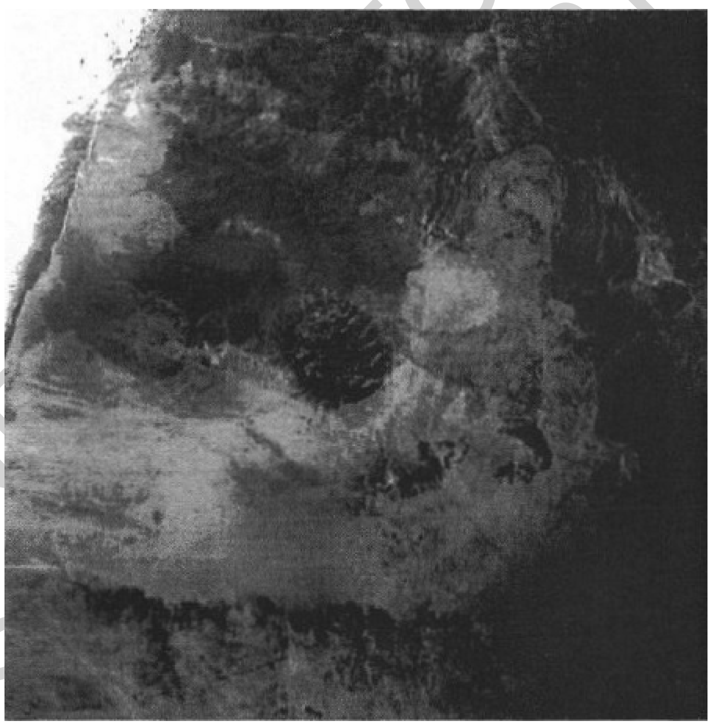

Figure 1. Hand-held Shuttle photograph of an area 150 km x 150 km of the Namib Desert
(*Source*: F.D. Eckardt, M.J. Wilkinson and K.P. Lulla, Using digitized handheld space shuttle photography for terrain visualization, *International Journal of Remote Sensing* **21** (2000), 1–5)

We shall make a few observations about each of these in turn.

As far as remote sensing is concerned, the rocket or launcher is obviously crucial. The details of rocket design and technology are not central to the theme of this article. We simply note that the larger and more massive a spacecraft, the more massive and more expensive will be the rocket required to launch it. In the early days, spacecraft tended to be small and to carry only one instrument. Over the years, they have tended to be made larger in order to carry several instruments. One extreme example is that of Envisat **(see Section 10.3. The European Space Agency's Program)**, with 10 instruments on board. However, for various reasons, the current trend is to revert to small satellites carrying a single instrument dedicated to a particular task. Details of the technology of spacecraft bus and solar panel arrays are not central to the main theme of this article, either; we simply assume that the necessary technology exists and can be purchased. What is more interesting is the nature of the instruments that have been developed for flight in space for remote sensing work, the choice of orbits for the spacecraft, and the nature of the data that can be recovered from these instruments. It is also interesting to consider the arrangements that exist on the ground for the reception, archiving, distribution, analysis, and interpretation of the data.

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