Introduction and History of Space Remote Sensing 26

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Abstract

This chapter introduces the subject of remote sensing both in terms of its technology and its many applications. Remote sensing via satellite has become a key service that is used in many civil applications such as agriculture, forestry, mining (and prospecting for many types of resources), map making, research in geosciences, urban planning, and even land speculation. Perhaps, one of the most vital uses of remote sensing today is related to disaster warning and recovery. The first use of remote sensing was essentially for military purposes and this remains the case today, and, thus, this chapter addresses these applications as well. Remote sensing, Earth observation, related Geographical Information Systems (GIS), plus the interpretation and use of this type of data are today often referred to today as Geomatics.

This section starts with a history of remote sensing and then continues with a discussion of the technology and its applications. In a number of ways meteorological or weather satellites are essentially a specialized form of remote sensing satellites. Thus the history presented here covers the not only what are considered remote sensing satellites but meteorological satellites as well.

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The meteorological satellites are discussed in much greater detail later in this Handbook.

Keywords
Corona • Cosmos • Earth resources technology satellite (ERTS) • Geographical information systems (GIS) • Geomatics • Geostationary orbiting environmental satellites (GOES) • Hyperspectral sensing • Infrared sensing • Landsat • LIDAR • Multispectral sensing • National ocean and atmospheric administration (NOAA) • Optical sensing • Pixel • Polar orbiting environmental satellites (POES) • Polar sun synchronous orbit • Radar sensing • Remote sensing • Resolution • Sensor • SPOT • Television and infra-red observation satellite (TIROS) • Zenit satellites of the Soviet Union

Introduction

Humans have always sought the high ground looking for food, exploring new lands, and watching for danger. Seeking the heights is an activity as old as the human species itself, as old as our urge to explore and discover. As technology has continually developed, we have found new ways to provide this important capability with greater precision and with greater coverage. As our capabilities have increased, we have also have found many new uses for that view from on high. Remote sensing can be defined as the art and science of acquiring information from sensors or systems that are not in direct contact with the objects being studied. The first practical remote sensing systems used photographic cameras, or simply the viewer's eyes, from balloons, kites, and even small cameras attached to pigeons. The development of aircraft and the rapid technological innovations of the first and second world wars created practical aerial remote sensing capabilities that have helped to map and understand our world.

The dawn of the space age was the next logical extension of this, by now quite important, aerial view of the Earth. Indeed, both the Soviet Union and the United States were quick to see the tremendous potential of space remote sensing for military reconnaissance, weather prediction, environmental analysis, and other applications. The original photographic systems used film and photographic prints to capture data. Over time more and more sophisticated sensors were developed to capture data across an ever broader range of spectra – both above and below visible light and the visual range available to the human eye. Over time an interpreter's skill in analyzing remote sensing data has given way to modern electro-optical systems and digital computers that help us to acquire, store, and analyze data about not only our Earth but our neighboring planets as well.

Over the decades since the first military remote sensing satellite launches in the 1950s, the technology has developed tremendously, and we are now in a very different situation from the cold war era. Today, many nations are developing, launching, and operating their own remote sensing satellite systems for a wide variety of civil, commercial, and strategic applications.

Satellite remote sensing has changed the way that we think about our planet and has served as important stabilizing influences in the cold war era, and perhaps even more so in the post cold war era. This versatile technology has great technology transfer potential, and has served as the basis for our initial robotic exploration of the moon and other planets as well.

The Purpose of Remote Sensing and Geomatic Systems

This chapter of the handbook will cover what remote sensing is, how it has developed, how it is used, and where the technology and its many applications are going. It is particularly important to note that there is a new term of art called Geomatics. Geomatics refers to all forms of remote sensing that includes the sensing technology, the capturing and display of data on Geographical Information Systems (GIS), and the capturing and interpretation of all forms of remote sensing data.

History of Satellite Remote Sensing Services

The development of space remote sensing is an evolution of mapping and cartography, which has its origins in many cultures around the world. Accurate maps were created and used in ancient Mesopotamia and Egypt over 3,500 years ago. Eratosthenes (276–195 BC) measured the circumference of the Earth and divided the Earth into 60 even grids, and Hipparchos of Nicea (165–127 BC) defined our 360° system that is still in use around the world today. It was in Ptolemy's *Geography* that the world was first defined within an even more precise system of degrees, minutes, and seconds of longitude and latitude. In China, the Chou emperors (1,100 BC) had royal geographers and Phei Hsui (267 AD) had a detailed set of maps created that covered all of the lands within the Chinese domain. The era of European exploration in the sixteenth through eighteenth centuries created a flourishing of cartographic techniques and methods that laid the foundation for accurate mapping and analysis of our world.

Even before the development of aircraft, people were finding ways to look from above, and the first recorded aerial photo was taken of Boston, Massachusetts in 1860 by Samuel Archer King from a balloon. In the American civil war balloons were used for military observation, and Dr. Julius Neubronner patented a miniature pigeon camera system in 1903 that worked quite well. Gaspar Felix Tournachon, known as "Nadar," photographed Paris from his balloon in the 1860s and Alfred Nobel developed a photo-taking solid rocket in 1897. The US Army Signal Corps used a series of large box kites to photograph the damage of the April, 1906 great earthquake and fire in San Francisco (see Fig. 26.1), California, and the pictures

Fig. 26.1 Kite-based photographic image of San Francisco in 1906 (Image courtesy of the US Geological Survey)

were prominently used by newspapers throughout the USA to rally relief support, the first known use of remote sensing for disaster response, which is now a very common application (Madry and Pelton 2010).

The development of the airplane and the military needs of World War one caused a huge improvement in aerial reconnaissance, which was quickly followed by a growing commercial aerial mapping industry. The Second World War produced the next great leap in the development of advanced cameras, films (including the first infrared film to defeat camouflage), image interpretation, and other advanced systems. After the war there were thousands of surplus aircraft and aerial cameras, trained pilots and landing fields throughout the world that spurred the next leap in aerial mapping systems, and the development of the German A4/V2 rockets laid the foundation for space remote sensing systems.

Modern remote sensing systems all derive directly from cold war military needs and capabilities. The Soviet Union and the USA shared an intense desire to acquire reconnaissance capabilities capable of covering large areas deep inside the other's territory. The Soviets authorized their Zenit spy satellites in 1958, only months after the flight of Yuri Gagarin, which used the same Vostock capsule. A total of 10 of the first 20 Cosmos series launches were Zenit systems, carrying four cameras that could acquire 1,500 individual photographs of the Earth per mission. The entire capsule was then deorbited and the cameras refurbished and reused.[1]

At the same time, the USA approved their Corona system in 1958, with the first launch and film recovery in 1960. The Corona was one of the most secret of US military program, and suffered 13 failures in a row before the first useable film was recovered. The exposed film was deorbited in a reentry capsule that was snagged in midair, while the entire satellite was deorbited and burned up upon reentry. The Corona program ran through 1972 and mapped over 5.5 million square miles in over 100 missions, an amazing technological feat at that time.

Fig. 26.2 Image from Corona satellite of the US Pentagon (Image from US Defense Department Archives)

This satellite, in its time, was by far the highest resolution imaging satellite available in Earth orbit. While it was one of the most secret military programs of its day, the Corona images are now available online and are available for use for long-term environmental analysis (see Fig. 26.2). The direct descendants of these early systems are flying today, continuing to push the development of the technology and providing an important stabilizing factor in global geopolitics.[2]

The first explicitly civil satellite remote sensing system was the US TIROS, the Television and Infrared Observation Satellite. While it started as a defense department initiative, it was transferred to NASA in 1959 and launched in April of 1960. It was not in a polar orbit, as is standard now, and had very poor spatial resolution by our standards today, but it quickly demonstrated the tremendous potential that satellite imaging could have for a variety of applications including weather, ice monitoring, ocean studies, and more. Nine more TIROS satellites followed, and the program was later moved to NASA, and its descendants continue as the National Ocean and Atmospheric Administration's (NOAA's) Geostationary Operational Environmental Satellite (GOES) and Polar Operational Environmental Satellite (POES) systems.

The Landsat program was the first systematic moderate resolution civil remote sensing system. It was started in 1970 and the first satellite was launched on July 23, 1972, only 2 years later. The Landsat program was first conceived in 1966 as a direct outgrowth of the successful Mercury, Gemini, and Apollo astronaut photographs, and was originally named ERTS, for Earth Resources Technology Satellite. The Landsat system continues in operation and it has generated years of broad synoptic coverage of our planet and originated hundreds of scientific applications and commercial uses.[3]

France launched their very successful SPOT program in 1986 that became the first system to produce remote sensing data for commercial consumption.[4] Once this process of collecting remote sensing data by satellite for commercial distribution became established the idea caught on quickly. Today, there are over 30 nations around the world operating a wide range of satellite systems that fall into several general categories. The Geostationary weather satellites provide a broad, synoptic coverage of our planet and are primarily used for continental scale weather forecasting and severe weather monitoring. These are operated as governmental organizations as a public good, but many of the other remote sensing satellite systems now offer commercial services to a global customer base although some restrictions often apply.

The optical systems in polar orbit can be grouped into low (1,000–250 m), medium (100–30 m), high (30–5 m), and very high (less than 5 m) spatial resolution. Currently available commercial satellite data of as little as 35–50 cm spatial resolution can be purchased today. This is a truly amazing transition from the first highly classified military satellites to a global commercial market for high-resolution images of the Earth. Active microwave systems using radar are also operating as civil systems, providing a very different and useful view of the Earth. All of these systems share common parameters and provide us with a continuous stream of data about our planet.

The latest evolution is reflected in the deployment of remote sensing satellites with hyperspectral imaging sensors. These satellites instead of sensing a broad range of the spectrum, provides the ability to break down imaging into very narrow bands. The data output from these sensors is deployed in so-called "data cubes" with the "x" and "y" axis being able to depict a spatial area and the "z" axis in the data cube showing the results across narrow spectral bands.

Hyperspectral imaging presents a very difficult issue in terms of processing the data since it requires a broadband downlink to send the data back to Earth and it presents a very difficult issue as to how to analyze and interpret the mountain of data generated by such imaging. The amount of data provided in hyperspectral sensing (since it may be collecting data over 200 different narrow spectral ranges) is so large, one can really only process by computers. Hyper-spectral sensing can produce almost two orders of magnitude greater data than is the case with multi-spectral sensing. This is because data is collected in very narrow spectral slots (i.e. up to 200) rather than across five to ten broad bands.[5]

Overview of Satellite Remote Sensing Services

Remote sensing satellites now provide the world with an amazing variety of information about our spaceship Earth. Two primary orbits are used, a Sun-synchronous polar orbit, often between 500 and 800 km, provides high and moderate resolution coverage of the entire planet on a regular basis. This special orbit allows a satellite to pass over the same location on the Earth periodically at the same time of day and with the same solar illumination. The satellite has to shift its orbit by approximately 1° per day as the Earth orbits around the Sun to achieve this periodicity. These types of satellites provide data for uses as varied as land use planning, forestry, military reconnaissance, and natural resources monitoring. Weather satellites in the geosynchronous arc provide a constant view of a portion of the globe at a lower resolution, but with a constant view. A ring of these, operated by several nations, now provide a constant world-wide watch over our planet for severe weather and broad climate applications.

By themselves, each of these capabilities are useful, but the integration of different types of remote sensing data, along with other types of information for various sources, are driving many new scientific investigations, practical applications, and commercial markets. Geographic Information Systems, or GIS, allows the integration of remote sensing data with population and other demographic data, in situ environmental telemetry, GPS positioning, and other relevant data. GIS has now become such an important way of depicting information in a useful and integrated way that it now represents a larger commercial market than remote sensing.[6] There are important and developing political, legal, social, and dual-use issues with all of these technologies, and these will continue to evolve as newer and more powerful systems and applications become available. The fact that over 300 million people now have access to Google Earth is a powerful demonstration of the impact and utility of geospatial data combined with high-resolution remote sensing imagery.

Remote sensing is a very complex and technologically advanced process, and includes a complex chain of end-to-end data flow and image processing, in order to deliver useful data to the end user. It is quite an achievement that a sensor on a satellite, moving at 8.5 km/s at some 800 km above the Earth, can collect, store, and transmit data to the ground that can be processed into the images we have become familiar with today on Google Earth and other sources.

The fundamental process of extracting useful information from remote sensing data relies upon the fact that objects that are of similar physical makeup can be identified by analyzing the energy that is reflected or emitted from it. This "spectral signature" is unique to each type of matter, and this allows us to discriminate between clean and polluted water, mature or immature crops, healthy or diseased forests, etc.

At the heart of each remote sensing system is a detector, which is the heart of the system. Energy is emitted from the Sun and some small fraction enters the Earth's atmosphere, interacts with the surface, is reflected or emitted from the surface back through the atmosphere, and falls upon the detector in a satellite after passing through the system's optical telescope. Most passive remote sensing detectors are designed in accordance with the photoelectric effect, and there will be an emission of negatively charged particles (electrons) when a negatively charged plate of an appropriate light-sensitive material is subjected to a beam of photons.

These electrons can then be made to flow from the plate, collected, and measured as an electrical current or signal. After some noise reduction and other preprocessing, the signal is digitized on the satellite and is transmitted to the ground, where an extensive ground processing system further processes the data to produce the data which are then available for use. Image processing and remote sensing specialists further process the data to extract useful information about our world. Most passive remote sensing data are in a raster, or two-dimensional numerical array format, with a single digital value for each area on the ground where the sensor was focused for some milliseconds. This instantaneous field of view (IFOV) is the pixel size of the data, and represents the spatial resolution of the image.

Other important resolution parameters include the temporal resolution (or how often the sensor samples the same location on the ground), the spectral resolution (or which part of the electromagnetic spectrum is measured), and the radiometric resolution (or how finely the signal can be measured). These resolution parameters define the characteristics of the sensor, and are used to determine which data are useful for a given application. Active radar and lidar systems work in a very different manner and are more complex, but, in the end, are processed into similar raster imagery for analysis or integration into a GIS.

There are many exciting new developments in the field of satellite remote sensing. These new developments include: new higher resolution systems operating down to 35 cm per pixel, hyperspectral sensors, high resolution radar systems, new artificially intelligent processing techniques, as well as a range of new applications. The entire field of geomatics is evolving both in terms of its technology, applications, and data display capabilities. The key remaining issue is the extent to which geomatics is to continue to evolve as largely a governmental service offer to citizens as a public good much like meteorological satellite services or whether it will evolve as a commercial service to support an array of newly evolving commercial markets. Clearly some vital remote sensing services such as to support disaster warning and recovery services and those related to coping with climate change will remain as a public service supporting the public good, but others new services may evolve on a strictly commercial basis.

Conclusion

The chapters that follow in this section seek to provide a comprehensive and interdisciplinary overview of satellite remote sensing technology, services, and applications. These chapters also seek to address to some degree the relevant markets, economics, operations, regulation, and future trends. The specifics of spacecraft design and technology for remote sensing and other applications satellites are not addressed in detail here. Many aspects of these technologies have already been addressed in the earlier section on telecommunications satellites. Thus a consolidated approach related to all applications is taken by combining this information in Sections 6 and 7 of the Handbook.

Section 6 of this book thus addresses the common technical elements found in essentially all applications satellites in terms of power systems, spacecraft bus technology and structural design, and on-board thrusters systems. Specifically, Section 6 addresses solar, battery, and nuclear spacecraft power systems; thermal balancing and heat dissipation systems; orientation, pointing and positioning systems; structural design elements; diagnostic systems; tracking, telemetry and command systems; manufacturing and integration; and quality and reliability testing processes.

Section 7 addresses how the various applications satellites are launched by different rocket systems from various launch sites around the world and the differences between solid, liquid, and hybrid launching systems.

Remote sensing satellites represent the smallest of the various space applications in terms of market size, but the application of this technology is of utmost importance. Today remote sensing satellite are used to undertake disaster recovery, carry out environmental and climate change science, while remote satellite imaging is actively applied to an ever-increasing number of economic fields that include agricultural, forestry, fishing, mining, and industrial applications and services. The commercial market for satellite-based remote sensing may be small in comparison to a field like space telecommunications but the critical importance of the global applications makes this field enormously large.

Cross-References

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▶ Digital Image Processing: Post-processing and Data Integration
▶ Electromagnetic Radiation Principles and Concepts as Applied to Space Remote Sensing
▶ Electro-optical and Hyper-spectral Remote Sensing
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