Chapter 1
Space Techniques for Earth Observation

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Abstract Features on Earth's surface remained undiscovered for long time and the interlinkage between these features was undefined until human was initiated conventional tools to figure out all these feature in one view from above. Thus, space techniques have been created with simple launching of sensors and cameras at heights to observe all objects on Earth's surface. This has been developed from low-flight by airplanes to space shuttles that can turn around the Earth along define orbital rotation. Therefore, the era of Remote Sensing has been existed since early 1990s, and tens thousands of these space shuttles, represented mainly by satellites, are rotating and capturing data on different themes required to be investigated. There are numerous of Land Observatory satellites retrieving daily images from hundreds of kilometers above Earth's surface and then transmitting these images for to receiving station which became widespread. Recently the use of space techniques in studying Earth's features has been rapidly developed, and the remote sensing techniques and its complimentary geo-information systems are new tools implied in many institutions and they became a primary tool for the management of Earth's resources. These tools have a wide spectrum of applications, on terrestrial and marine environments, including mainly the monitoring approaches, resources assessment, change detection, natural hazards assessment. This chapter will demonstrate a detailed discussion on these techniques with a special emphasis on satellite images and their specifications.

Keywords Satellite image · Polar orbit · Spatial resolution · Geo-spatial data · GIS

1.1 Concepts and Definitions

Natural resources, environment, infrastructure as well as human are usually under natural risks which is resulted in severe damages and destruction of major components on Earth's surface. Traditional methods for the analysis of these risks has been

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initiated since few centuries when urbanism has taken place over wide geographic areas and the number of natural risks have been exacerbated.

Primarily, maps were utilized along with field surveys and investigations and accompanied with laboratory tests. Thus, people has long identified the importance and value of maps in several topics notably those belong to surficial processes on Earth's surface. In fact, the history of mapping can be referred to some thousands of years ago, and this remained until the last few decades when maps production was following traditional methods of cartography. These methods were primitive whether in terms of the acquirement of data and information on terrain surfaces and the existing processes or in the ways by which these maps were drawn.

Nowadays, mapping is represented mainly by topographic maps (i.e. base maps) or charts, which are characterized by large-scale dimensions and variety of quantitative representation of vertical and horizontal features of terrain surface that are illustrated as contour lines (i.e. virtual lines with equal elevations). These maps were primarily extracted from aerial photos that are acquired by aircraft or by any low-flight shuttles. Aerial photos, which have a miscellany of specifications and are interpreted by stereoscopic analysis, represent the beginning of Remote Sensing era when the first recorded photograph was taken from an airplane by Wilbur Wright in 1909. This led to the development of science of photogrammetry which enables applying analysis and measurements for the Earth's surface.

Recently, stereoscopic photographs and satellite images can produce topographic maps with high accuracy, and then enabling the extraction of thematic information in order to apply several calculations and analysis on the topographic maps. Therefore, satellite remote sensing has been used for topographic mapping purposes since the launch of ERTS-1 in 1972 (Dixon-Gough, 1994).

Recently, the use of space techniques has become a common tool in many regions and they are applied for different applications, including natural resources and surficial processes. In a broad sense, these techniques tackle the processing of digital (i.e. electronically produced) satellite images and remotely sensed products, which are significant instruments used to draw maps, identify, analyze and measure the observable terrain features that are reflecting several natural and anthropogenic processes (Al Saud, 2020).

The following are significant definitions belong to space techniques including their specifications and applications:

- Remote Sensing (RS): It is recently described as a science of exploring and monitoring Earth's components from space. It is therefore, the process for detecting and monitoring the physical characteristics of the objects on Earth's surface without physical contact with these objects. RS depends mainly on measuring the reflected and emitted radiation on Earth's at a distance (typically from satellite or aircraft).

GIS: The Geographic Information System is computer-based system of hardware and software capable to display and manage information about geographic localities, analyze spatial relationships, and model spatial processes.

– Temporal resolution: The frequency at which images are captured over the same location on the earth's surface.
– Sensors: A device (e.g. camera) mounted on satellite to collect data by detecting the energy that is reflected from Earth.
– Pixel: is a physical point in a raster image, or the smallest controllable element of a picture represented on the screen.
– Digital number (DN): It is a variable assigned to a pixel where it represents a binary integer in the range of 0–255 (i.e. a byte). Thus, a single pixel may have several digital number variables corresponding to different bands registered.
– Raster image: Is a pixel-based image, called also a "bitmap", where the latter is a grid of individual pixels that collectively compose an image.
– Vector image: This refers to vector graphics are based on mathematical formulas that define geometric primitives such as polygons, lines, curves, circles and rectangles.
– Radar: Acronym for radio detection and ranging. A device or system that detects surface features on the earth by bouncing radio waves off them and measuring the energy reflected back.
– Space shuttle: *A space* Transportation System, partially reusable rocket-launched vehicle designed to span into orbit around Earth. It often carry sensors, human or cargo.

1.2 Space Techniques

There are different types of space techniques where sensors are mounted of platforms or shuttles forming satellites that travel in space and follow define orbital turns. Up to date, there are more than sixty thousand satellites have been lunched to the space around the Earth, and many of them are now non-functional.

Thus, there are the communication and land (or Earth) observatory satellite images where the first is concerned in the communication purposes (e.g. radio, TVs, GPS, etc.), while the observatory satellites are acquiring images to the Earth's surface including the marine and terrestrial environments. For the latter, it has been assigned as the science of "Remote Sensing"which has a wide spectrum of applications and it is being rapidly developed.

Satellites follow two orbiting traverses; these are either polar or geostationary orbiting. Hence, meteorological satellites and most of the communication satellites follow the geostationary orbit, while land observatory satellites travel along the polar orbit (Fig. 1.1).

Therefore, Remote Sensing is the process of geo-spatial data acquisition from satellites, aircraft, and lately drones, etc. therefore, satellite images, aerial photos, thermal images, Digital Elevation Models (DEMs), etc. are produced. The acquired geo-spatial data is derived from the electro-magnetic radiation (EMR) which is reflected and emitted from the objects, with different physical characteristics, on Earth's surface. Even though, the flight characteristics of the platforms are

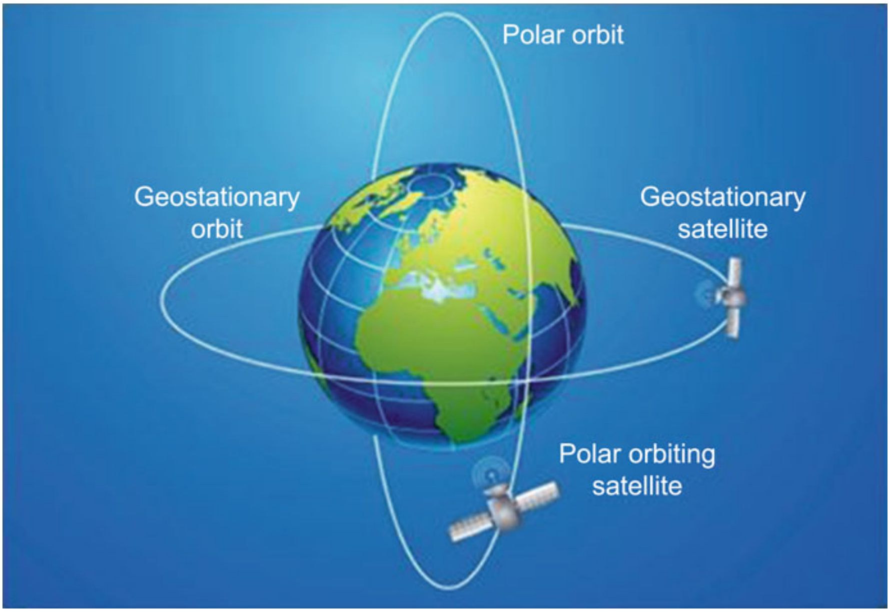

Fig. 1.1 Polar and geostationary orbiting satellites

significant for the resolution of the acquired geos-spatial data, yet sensors on satellites are the most significant in this respect.

This electromagnetic energy, as electric and magnetic disturbance, propagates in media (e.g. atmosphere) and spans a broad spectrum from very long radio waves to very short gamma rays. The electromagnetic spectrum is classified by wavelength that ranging from 10 to 10 mm to cosmic rays up to 1010 mm, and the broadcast wavelengths, which extend from 0.30 to 15 mm.

Two types of remote sensing sensors are known to acquire the electromagnetic radiation. They are the passive (optical remote sensing) and the active (microwave, or radar) sensors. Passive sensors detect the naturally radiation reflected or emitted by the objects on Earth's surface, whereas active sensors transmit their own energy for illumination which is directed toward the target to be identified, and then it capture the reflected radiation reflected from that target.

Remote sensing can be classified with respect to the type of radiation captured by sensors and the ranges wavelengths, as follows:

– Visible and Reflective Infrared RS,
– Thermal Infrared RS,
– Microwave (or radar) RS.

Sensors on platforms have different optical and spectral specifications, one of them is the altitude above Earth's surface, as well as the time needed to complete a turn around the Earth. The most known platforms are: 1) satellites (altitude: 500–900 km), 2) space shuttle (altitude: 185–575 km), 3) high-latitude flying aircraft (altitude: 10–12 km), 4) moderate-latitude flying aircraft (altitude: 1.5–3.5 km) and 5) low-latitude flying aircraft (with altitude below 1 km).

The first lunched remote sensing satellites, namely Sputnik, 1957; Explorer, 1958 and Corona, 1960 have been widely used and many innovative techniques were developed since then. Thus, remote sensing has a very wide range of applications in many different fields including (but not limited) water resources, marine environment, coastal zones management, agricultural, natural hazards, change detection and monitoring, marine pollution, etc.

Satellite remote sensing is a wide topic with many applications, including solid earth science, physical oceanography, land/ocean biology, cryosphere science, atmospheric science and near-earth space science. There is a vast array of passive and active sensors currently in orbit around the Earth providing a wealth of remote sensing products that are transformed into information using a variety of techniques and tools. Learning the entire field would require studying perhaps a dozen books on the topic. Physical principles of remote sensing: third edition does not attempt to cover all these tools and applications but instead exposes the basic physics and chemistry underlying remote sensing methods (Sandwell, 2013).

1.3 Satellite Images

First aerial photograph was simply practiced from a balloon flew over Paris in 1858. However, the produced aerial photograph was no longer exist, and then the earliest surviving aerial photograph, which was taken also from a balloon and entitled "Boston", was taken in 1860. Therefore, photography and photogrammetry have been rapidly developed, and then widely used notably for the military purposes during World Wars I and II.

Photography, as the beginning of remote sensing, proved to be a significant tool for visual interpretation and the production of analog maps. However, the development of satellite platforms during 1950s, the associated need to telemeter imagery in digital observation, and the need for consistent digital images have given the chance for the development of sensors as a fundamental format for the capture of remotely sensed data.

Nowadays, several satellite systems are in operation in collecting images that is subsequently distributed to users. Each type of satellite data offers specific characteristics that make it more or less appropriate for a particular application (Eastman, 2001).

Usually, identifying the specifications of a satellite image is significant, they are often determined as a first step forward while determining the tools of analysis in studies and projects. In this regard, many specifications characterize satellite images. We illustrate the most significant one as follows (according to Al Saud, 2020):

1. Spatial resolution:

The pixel size recorded in a raster images is described as “spatial resolution“. Where the pixel is the smallest controllable element of a picture represented on the screen. Hence, the pixel size enables distinguishing features, and then the pixel in satellite images controls the clarification and discrimination of objects on Earth’s surface. In this regard, the compound remote-sensing system is significant, including lens antennae, display, exposure, processing and many other specifications to achieve well recognizable image.

Images with low-resolution are characterized by large pixel size where they do not show objects as clearly as in high-resolution images. Hence, satellite images, from different sensors, have different spatial resolution (example Fig. 1.2) that ranges from tens of centimeters (e.g. Geo-Eye, 41 cm; Quick-bird, 61 cm) up to few of kilometers (e.g. NOAA, AVHRR, 4 km).

2. Spectral resolution:

Spectral resolution is defined as the band range or band width reported by the sensor. Thus, it is the ability of a sensor to highlight fine *wavelength* intervals. Therefore, the finer the *spectral resolution,* the narrower the *wavelength* range for a particular channel or band. For example, the satellite image of Landsat sensor has seven bands, some of them are in the infrared spectrum, where the spectral resolution ranges between 0.7 and 2.1 μm. Besides, the satellite image of Aster sensor has 14 spectral bands where 3 of them are in the visible range and 11 in the infrared range.

3. Revisit time:

This is also the return rime, or it is often described as the temporal resolution of the image where it is attributed to the temporal frequency of sampling by repeat imaging. In other words, it is defined as the time needed by the satellite to comeback over the same point on Earth’s surface. The revisit time turn depends on the orbitography of the platform or satellite on which the sensor is mounted. In addition, most of the Earth observation satellites having quasi-polar orbits, thus the frequency of revisits is also depending on the latitude of the area of study. Therefore, it is important for remote sensing element, notably in mapping and monitoring approaches.

The temporal resolution (or revisit time) on the satellite image does not belong to its spatial or spectral resolution. For example, Landsat (30 m) and Aster (15 m) require 16 days to make one turn around the Earth, while the revisit time of Spot-6 (6 m) is 26 days.

4. Swath width:

Swath width describes the area imaged on the Earth’s surface. Thus, it is the areal coverage that sensors can viewed and imaged, and then capture settled image size, which is called as “image scene”. Hence, in aerial photogrammetry, swath width mainly depends on flight altitude type; nevertheless, the altitude has no essential effect in swath width for images retrieved by satellites which it depend mainly on the specifications of the sensor (Al Saud, 2020).

Fig. 1.2 Satellite images with different spatial resolution (Spot-5 with 5 m and Quick-bird with 0.61 m; the Quick-bird image is indicated in the white frame above in the Spot image)

Table 1.1 Example of commonly used land observatory satellite images.

Satellite	No of Bands	Spatial resolution	Revisit time	Swath width (km)
Worldview-4	6	0.31m	1.7 days	13.1 × 13.1
Geo-eye	5	0.50 m	2.8 days	15.2 × 15.2
Kompsat-6	6	0.50 m	28 days	30 × 30
Quick-bird	5	0.61 m	1–3 days	16.5 × 16.5
IKONOS	5	0.82 m	3 days	11.3 × 11.3
Rapid-eye	5	5 m	5.5 days	77
Sentinel-1A	13	5 m	6 days	250
SPOT-7	4	1.5 m	26 days	60 × 60
Aster	14	15 VNIR, 30 m SWIR, 90 m TIR.	16 days	60 × 60
IRS 1D	4	23 m	5 days	70 × 142
Landsat 7 ETM +	8	30 m, 120 m thermal, 15 m pan	16 days	183 × 183
Landsat 8 OLI-TIRS	14	30 m, 100 m thermal, 15 m pan	16 days	183 × 183
MODIS	36	250 m, 500 m, 1 km, 2 km, 4 km	Twice/day	2030 × 1354
AVHRR	4	1.1 km	Twice/day	3000

Even though, it is not often the case, yet many satellite images with big swath width are found with low spatial resolution; in spite that swath width and image resolution have no relationship. For example, a Sentinel-1 image has a swath width of 80 × 80 km, while it is 60 × 60 km for Aster and Spot-7 satellite images.

In this regard, image specifications, especially those acquired by satellites, are significant prerequisite for the selection of an image to be analyzed as shown in Table 1.1.

1.4 Satellite Image Processing

The available digital raster images of spectral reflectance data is resulted from the solid state multispectral scanners and other raster input devices. The advantage of having these digital data implies enabling to apply computer analysis techniques to the image data-a field of study called Digital Image Processing (Eastman, 2001). Thus, the efficiency of satellite images is mainly based on their optical and spectral specifications which are significant in the assessment and study of different terrain themes including mainly monitoring approaches, natural hazards assessment, change detection, etc.

For example, observing Earth's surface from space using by Ikonos satellite images enables clearly distinguishing objects with approximately 0.82 × 0.82 m area, and this is more likely to observe these objects from about100 m altitude. This virtually means that mankind can fly over any area and look down and distinguish all objects exceed 0.67 m^2, but this observation can be each 3 days only. Thus, different type of satellite images are used for several purposes to attain dates overlapping, and utilizing from the spatial resolution of one image to another, etc. (Al Saud, 2020).

This is why is must be made clear the selection of appropriate satellite images before starting the processing of these images. This includes, in a broad sense, the spatial and spectral resolution, swath width and the revisit time. In addition, the knowledge on and expertise to analyze these images using proper computerized devices is significant. Moreover, there are many other specifications to be considered while selecting satellite images, such as the spectral and electronic properties, number of bands, their wavelength and spectrum ranges (e.g. thermal band, micro-wave, optical band, etc.).

Usually, the availability of proper satellite images is a constraint. This makes it necessary for many countries to establish space center where they can retrieve a considerable number of satellite image for research and commercial application. In this regard, the Kingdom of Saudi Arabia is a typical example in the MENA Region where the Space Research Institute has been established at the King Abdulaziz City for Science and Technology (KACST).

The digital (electronic) raw data and the appropriate software for image processing are the main two components to be ready in order to start the analysis of satellite images. In this regard, there are several software types used, the most commonly ones are:

– ENVI Image Analysis: Produced by: *IBM*. Colorado, USA.
– ERDAS Imagine: Produced by: *Lucia*, Georgia, USA.
– PCI Geomatics: Developer of *Geomatica*, Toronto, Canada.
– ILWIS: Produced by *ITC*, Enschede, Netherlands.

Each software has define characteristics and follows different manners of use. Thus, the processing of satellite images implies the pre-processing steps and image analysis and classification. They can be concluded as follows:

1. Pre-processing: This represents the first step applied to prepare the images for further processing and classification. Therefore, satellite images can be analyzed after applying the following processes using the software.

   – Image sub-setting, which is the process applied to extract the area of interest (AOI) from the entire images scene. It is applied to have the lowest size and then to avoid the slow-down the work and any demanding on computing resources.
   – Atmospheric correction, is a process applied for noise removal and to clarify true surface reflectance where it is done by removing atmospheric effects from satellite images.
   – Geometric correction, which is the correction of noise and sun-angle which usually result in images displacement due to the altitude of shuttle-bearing sensor. Thus, registration is applied using “rubber sheet“transformation which warps the image on defined points.

- Geo-referencing, is a significant step to rectify the image for the assignment of geographic location, scale, and alignment to a file, and it is performed on raster and vector data to interrelate internal coordinate system to associate objects with locations in physical space.
- Mosaicking, is an opposite process for sub-setting, but in this case, multiple images on different separate scenes are interlinked together in order to have a unified scene for the AOI.

2. Image analysis and classification (processing): This is applied after the image has been prepared following the previous pre-processing steps. It is applied in order to recognize the existing objects on Earth's surface, calculating dimensions, monitoring changes and features, etc. This will follow two major methods:

   - Image enhancement and detection, where several digital and spectral applications are applied in the used software in order to reach the clearest observation and to distinguish objects as much as the resolution of the images allows. These applications are mostly tentative and their use is dependent on the knowledge of the analyzer.

The known applications of images enhancement are the: color slicing, edge detection, directional filtering, enhancement, interactive stretching, contrasting and sharpness. In addition, band combination which is also performed for the single band and multi-band where different band are ordered in different ways unless reaching the suitable observation.

- Image classification, "Classifier"on the software is used and it involves grouping the image pixel values into indicative categories. There are many types of image classification, and the most significant ones are the following: (1) Unsupervised classification by which pixels are grouped into "clusters" based on their properties, and the each cluster can be tentatively attributed to land class, (2) Supervised classification where the analyzer selects representative classes of land, and therefore the software utilizes these "training sites" and applies them to the entire image, (3) Object-based classification where pixels are grouped into representative vector shapes with size and geometry. It is not therefore similar to the supervised and unsupervised classification which are pixel-based (GIS Geography, 2020).

1.5 Geographic Information System (GIS)

Geographic Information System, also called "Geo-information System" is a computer-based system applied for the extraction, storing, drawing and the display of the geo-spatial data. It enables to expose different types of geo-spatial data on one display, such as forests, urban areas, streams, streets, pipelines, water bodies, etc. The use of GIS performs the easily observe, analyze, and understand patterns and relationships (NGS, 2020).

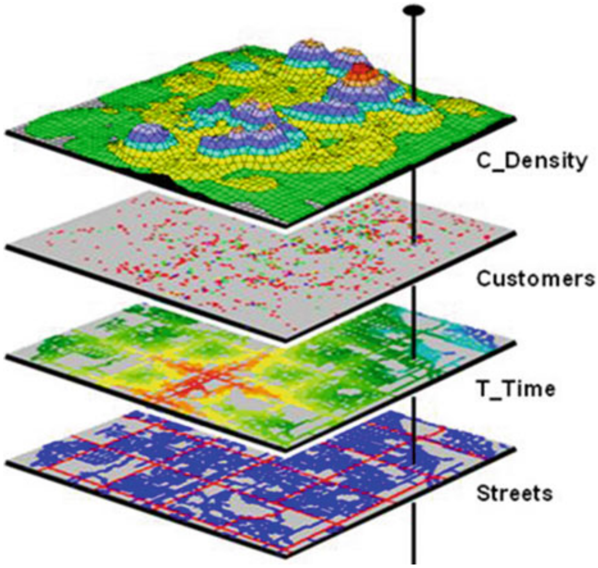

Fig. 1.3 Example showing the integration of different themes in the GIS system

The GIS technology performs applications on digital information, such as the digitization of the geo-spatial data, where hard copy maps or survey plans are transferred into digital data by using computer-aided design and geo-referencing capabilities. Therefore, GIS is used for mapping the locations, quantities and even qualities, densities, finding the inside and nearby features, change detection and many other applications of geo-spatial data illustration. It is therefore, applied in data modeling to overlap different digital maps (as layers) where each map has a define theme, and this enables integration of different themes into a unified figure (example in Fig. 1.3).

The increase in the use and sophistication of these systems has led to a new academic interest which has resulted in a vigorous and expanding research community (Clarke, 1986). Lately, the techniques of the geo-information system have been involved in the management planes and instrumentation in many institutions (e.g. authorities, research centers, universities, etc.), then these techniques became a primary tool for data management.

The manipulation of geo-spatial data in the GIS systems is performed using different types of software, which have been well developed recently and usually accompanied with Remote Sensing tools. Hence, ESRI (Environmental System Research Institute, Redlands, USA) is the major used software where it implies *Arc-GIS,* as the principal Geo-information system tool extended on ITS computers, and is installed in UNIX and Networked PC devices. Thus, *Arc-GIS* has three main digital components:

Arc-GIS, as a software, is utilized to generate, display and analyze geo-spatial data. It includes three digital components:

- *Arc-Map* which enables visualizing spatial data, performing spatial analysis and drawing maps.
- *Arc-Catalog* is a tool for browsing and exploring spatial data, as well as viewing a creating metadata and managing spatial data
- *Arc-Toolbox* is an interface for accessing the data conversion and analysis function the come from *Arc-GIS*.

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