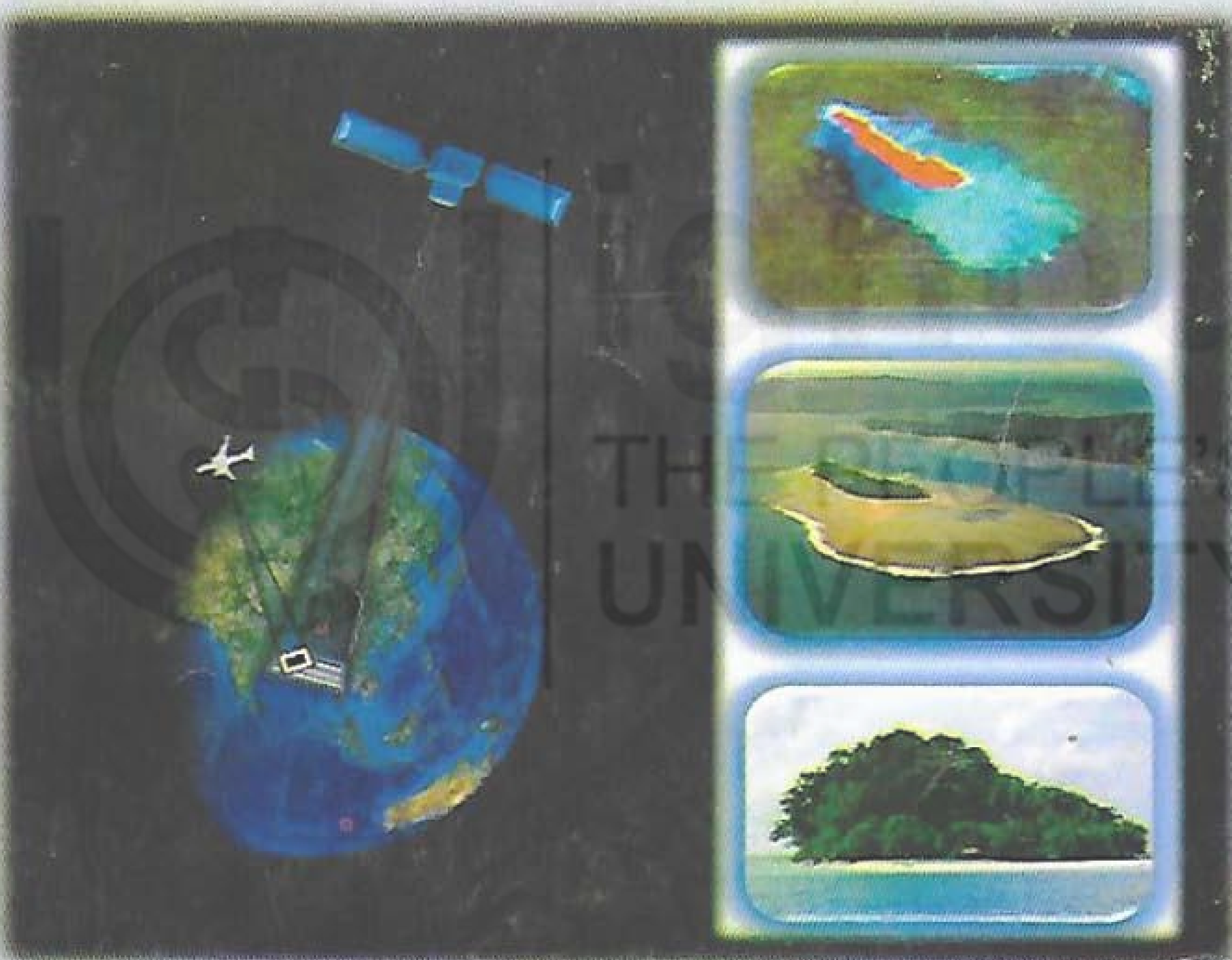
Indira Gandhi National Open University
School of Sciences

MGY - 002
REMOTE SENSING AND IMAGE INTERPRETATION



Sensors and Space Programmes

2

Indira Gandhi
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MGY-002
REMOTE SENSING AND IMAGE INTERPRETATION

Block

2

SENSORS AND SPACE PROGRAMMES

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BLOCK 2 SENSORS AND SPACE PROGRAMMES

In Block 1, you have studied about principles of remote sensing. You have also studied about spectral properties and signatures of common Earth materials. Properties of image features may vary depending upon the mode of image acquisition and sensor parameters. Hence, it is essential to study about platforms, sensors and related parameters to understand and identify image features. This block introduces platforms and sensors commonly used for remote sensing, sensor parameters and also about some major space programmes of India and the world through three separate units.

Unit 4 presents an overview of different types of platforms used for remote sensing such as aircrafts, satellites, space stations, etc. It also offers an account on types of satellites based on their applications including military and Earth observation, communication, weather satellites, etc. It also gives you an overview of the sensor systems working in the visible, infrared and microwave regions of the electromagnetic spectrum.

Unit 5 deals with one of the important parameters of sensors i.e. image resolution. Capability of a remote sensing data to provide details of the objects of interest is governed by the image resolutions. This unit begins with a conceptual background of image resolutions and then provides a detailed account on the different types of image resolutions for optical data. It also introduces different types of terminologies used in microwave sensor systems.

After studying about remote sensing platforms, sensors and the sensor parameters, it is now time to get an idea about major space programmes of the India and the world. **Unit 6** provides an overview of the important space programmes of India and other countries along with characteristics of important sensors. It also introduces some of the commercial space programmes.

Objectives

After studying this block you should be able to:

- list out and discuss about different types of platforms used for remote sensing;
- explain sensor systems and types of satellites used for different purposes;
- define image resolution and elaborate upon its types;
- describe major space programmes of India and other countries along with characteristics of the important sensors; and
- write achievements of Indian space programmes.

We hope that after studying this block you will acquire sound understanding of remote sensing sensors, platforms and major space programmes of the world.

UNIT 4 PLATFORMS AND SENSORS

Structure

4.1 INTRODUCTION

In Block 1, you have studied that remote sensing deals with acquiring information about target through recording the interaction between incident radiation and the target. Sensor is an instrument, mounted on a stable platform away from the Earth, which collects and records energy reflected or emitted from the target. The platforms orbit in space in different orbits either near or away from the Earth. Most of the remote sensing is performed from orbital or sub-orbital platforms using instruments (sensors) which measure electromagnetic radiation (EMR) reflected or emitted from the landscape. Design aspects of the sensor systems vary depending upon the wavelength regions on which the sensors operate. In this unit, we shall discuss about different types of platforms, their orbits and sensors.

Objectives

After reading this unit, you should be able to:

- discuss about different types of platforms used for remote sensing;

- explain satellite orbits and their types; and
- describe sensor systems and types of satellites used for different purposes.

4.2 REMOTE SENSING PLATFORMS

Platforms are commonly called the vehicles or carriers for remote sensing devices. A platform is a synonym for any orbiting spacecraft, be it a satellite or a manned station, from which observations are made. In most instances, the platforms are in motion and by movement they automatically proceed to new positions from where, they target new objects. A satellite orbiting the Earth is a typical platform however, the platforms range from balloons, kites (low altitude remote sensing) to aircrafts and satellites (aerial and space remote sensing). As we go higher in the sky, larger area is viewed by the sensor. Thus, the altitude determines the ground coverage, which is a key factor for selection of a platform. Besides the altitude of the platforms, there are other parameters which are responsible for determining ground coverage and resolution of image data and hence one platform may have different sensors acquiring data at different ground coverage with different image resolutions. Platforms equipped with remote sensors may be situated on the ground, on a balloon, on an aircraft (or some other platform within the Earth's atmosphere), or on a spacecraft or satellite outside the Earth's atmosphere. The three most common types of platforms as shown in Fig. 4.1 are:

The concept of resolution is given in Unit 5 *Image Resolutions,* of MGY-002.

- terrestrial platform
- airborne platform, and
- spaceborne platform.

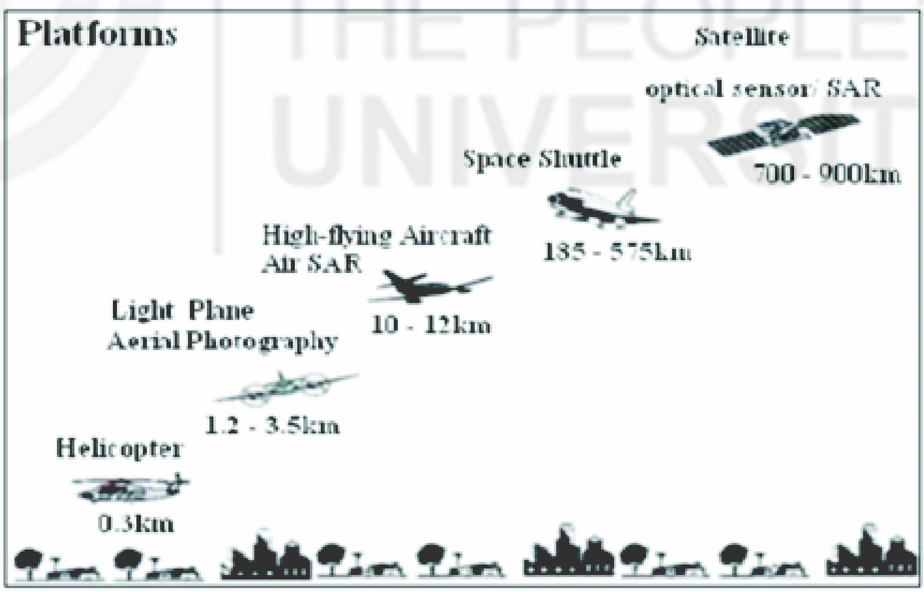

Fig. 4.1: Remote sensing platforms

Let us now discuss in detail about the types of platforms.

4.2.1 Terrestrial Platforms

These platforms range from simple tripods to booms, cranes and towers. Booms raise the sensor from 1 to 2 m above the object to be sensed and towers can reach tens of meters above the Earth's surface. Terrestrial platforms are also known as *ground-based* platforms because they remain in contact with the ground during the imaging of the Earth's surface. The ground based platforms are either static (on a stationary platform such as a tripod or mast) or dynamic (on a moving vehicle) used for close-range, high accuracy applications. These platforms work at short, medium and long range of 50-100 m, up to 250 m and 1000 m, respectively. Purpose of short range application is the mapping of buildings and small objects. Medium range sensor, with millimetres accuracy is used for three dimensional modelling applications. Long range sensors are frequently used for topographic application. Images collected from a close distance terrestrial platform have much greater spatial resolutions than those collected from the aircraft or satellites.

The data collected by terrestrial platforms are used for bridge and dam monitoring, landslide and soil erosion mapping, architectural restoration, facilities inventory, crime and accident scene analysis, manufacturing, etc. It is incorporated into surveying and metrology instruments and is often employed in mobile mapping systems.

Metrology is the science of measurement and it includes all theoretical and practical aspects of measurement.

4.2.2 Airborne Platforms

Aerial remote sensing started few decades ago with photographic (i.e. recording on film) cameras and the technology is now well established with the development of sensors. Airborne platforms such as airplanes, helicopters, balloons and even rockets are commonly used to collect very detailed images. Because they are capable of operating over a wide range of altitudes ranging from the sea level to stratosphere at an altitude of about 500 km, they facilitate collection of data over virtually any portion of the Earth's surface at any time. Aerial platforms are primarily stable wing aircrafts, although helicopters are occasionally used.

Aerial photographs have been a main source of information about the Earth's surface almost since the beginning of aviation more than a century ago. Aerial photographs are obtained using mapping cameras that are usually mounted in the nose or underbelly of an aircraft that then flies in discrete patterns or swathes across the area to be surveyed. Mostly propeller or Jet Prop aircrafts are preferred for this purpose because they fly slower, allowing easier film advance and also cost less to operate.

Aircrafts have following advantages as platforms for remote sensing systems:

- aircraft can fly at relatively low altitudes thus allowing for sub-meter sensor spatial resolution
- aircraft can easily change their schedule to avoid weather problems such as clouds, which may block a passive sensor's view of the ground
- last minute timing changes can be made to adjust for illumination from the Sun, the location of the area to be visited and additional revisits to that location
- sensor maintenance, repair and configuration changes can be easily made to aircraft platforms
- aircraft flight paths know no boundaries except political boundaries however, getting permission to intrude into foreign airspace could be a lengthy and frustrating process.

4.2.3 Spaceborne Platforms

Man made satellites are the examples of spaceborne platforms. Satellite based remote sensing is also referred as orbital remote sensing. Space transport system, commonly known as the space shuttle is also sometimes used as a platform. As you know satellites are objects which revolve around the Earth. For instance, the moon is a natural satellite whereas man-made satellites include platforms that are launched for remote sensing, communication, and telemetry (location and navigation) purposes. In space borne remote sensing, sensors are mounted on-board a spacecraft (space shuttle or satellite) orbiting the Earth. Because of their orbits, satellites permit repetitive coverage of the Earth's surface on a continuing basis. These orbits are fixed; a single satellite orbit can be adjusted slightly to maintain consistency over time but it cannot be changed from one orbit type to another. In spaceborne platforms, satellites are placed at three types of orbits around the Earth that are geostationary, polar and sunsynchronous orbits. These orbits are described in the next section. Space borne platforms are either of short duration, such as the space shuttle that remains aloft for 1-2 weeks, or of long duration, such as the Earth resource monitoring and meteorological satellites (e.g., Landsat, SPOT, AVHRR). At present, there are several remote sensing satellites providing imagery for a variety of applications.

Satellite remote sensing can significantly enhance the information available from traditional data sources because it can provide synoptic view of large portions of the Earth. However, resolution is limited due to the satellite's fixed altitude and orbital path flown. Spaceborne sensors are currently used to assist in scientific and socio-economic activities like weather prediction, crop monitoring, mineral exploration, waste land mapping, cyclone warning, water resources management and pollution detection.

Space borne remote sensing has the following advantages:

- large area coverage
- frequent and repetitive coverage of areas of interest
- quantitative measurement of ground features possible using radiometrically calibrated sensors
- semi automated computerised processing and analysis
- relatively lower cost per unit area coverage
- one obvious advantage satellites have over aircrafts is the global accessibility; there are numerous governmental restrictions that deny access to airspace over sensitive areas or over foreign countries. Satellite orbits are not subject to these restrictions, although there may well be legal agreements to limit distribution of data collected over particular areas of the globe.

Now, if you are confused about data from which platform to use, following explanation may help. One can say that the choice of platform depends largely on the application. The ground based platforms are frequently used to produce detailed 3D models of buildings, bridges, streetscapes, factories and other man-made infrastructure. Airborne platforms are effective for topographic mapping and engineering applications whereas spaceborne systems are immensely useful to map remote areas of the globe for scientific purposes. With launch of satellites concerned with specialised applications, satellite remote sensing data are also being increasingly used for topographic and cartographic applications hence, the boundary is slowly getting blurred. However, cost of data acquisition and the type of information that is to be derived from the data are two important criteria influencing our decision to opt for data acquired from a particular platform.

Check Your Progress I

Spend 5 mins

1) Name the platforms used in remote sensing.

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2) List any two advantages of aerial platform.

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4.3 TYPES OF SATELLITES

We have already discussed about the platforms, orbits and sensor systems of the satellites. In this section, we will discuss about different types of satellites. You are familiar with the fact that today man-made or artificial satellites are widely used for a large number of purposes including military and civilian Earth observations, communication, navigation, weather forecasting and research purposes. Hence such satellites are classified into six major types namely, astronomical, communication, weather, remote sensing, navigation and reconnaissance satellites based on their uses.

4.3.1 Astronomical Satellites

An astronomical satellite is basically a big telescope floating in space. The satellite's vision is not clouded by the gases that make up the Earth's atmosphere because it is in orbit above the Earth. Therefore, astronomy satellites can see into the space up to ten times better than a telescope of similar strength on the Earth.

Hubble Space Telescope (HST) is a space telescope that was carried into orbit by a space shuttle in 1990. Hubble is one of the largest and most versatile, and is well-known vital research tool. The HST was built by the United States space agency NASA, with contributions from the European Space Agency and is named after the astronomer Edwin Hubble.

Can you guess what kind of things an astronomy satellite would be looking at? Applications of astronomical satellites are mentioned below:

- to make star maps and take pictures of the planets in the solar system
- to study mysterious phenomena such as black holes and quasars, and
- also to make maps of different planetary surfaces.

Astronomy satellites are different from space exploration satellites because they collect their data from Earth's orbit. In real sense, space exploration satellites are probes that are sent out into deep space. The most famous Hubble Space Telescope is an example of an astronomy satellite.

4.3.2 Communication Satellites

A satellite used for sending messages for telephonic conversations and conferencing, television broadcast, FAX, computer related network services or other communication/transmission to long distances is called a ***communication satellite***. Communication satellites are commonly placed in the geostationary orbit. Now-a-days these satellites possibly form the greatest number of satellites that are in orbit. They are extensively used for the communication over large distances. It is really very difficult to go throughout a day without using a communication satellite at least once. You use communication satellites directly or indirectly while watching TV, in making long distance phone call, using a fax machine or even in listening to your favourite radio station.

Communication satellites allow radio, television, and telephone transmissions to be sent live anywhere in the world. A communication satellite is a radio relay station in orbit above the Earth that receives, amplifies, and redirects analog and digital signals carried on a specific radio frequency.

4.3.3 Weather Satellites

As the name implies these satellites are used for the monitoring and forecasting of the weather. They can provide a much better understanding of weather phenomena. And, because of this technology, you can find out weather condition anywhere in the world at any time of the day. These satellites provide meteorologists with scientific data to predict weather conditions and are equipped with advanced instruments. Weather satellites can give information about the followings:

- radiation measurements from the Earth's surface and atmosphere which give information on amount of heat and energy being released from the Earth and its atmosphere
- satellites monitor the amount of snow in winter, the movement of ice fields in the Arctic and Antarctic regions, and the depth of the ocean
- infrared sensors on satellites examine crop conditions, areas of deforestation and regions of drought.

4.3.4 Earth Observation Satellites

As you know remote sensing is observing and measuring our Earth's environment from a distance. So, remote sensing or Earth observation satellites are usually put into space to monitor the resources that are important for humans. Remote sensing satellites are generally placed in the sun synchronous orbit. Using these satellites it is possible to see many features that are not obvious from the Earth's surface. For example, remote sensing satellites might track animal migration, locate mineral deposits and exploitation, watch agricultural crops for weather damage, etc.

All of these things can be done best from space because a satellite in orbit can normally take photographs of large areas of land all over the world. Since these satellites are able to take images and observe areas all over the globe, the satellite is able to monitor areas in which the climate is very harsh, or which are nearly impossible to reach by land.

4.3.5 Navigation Satellites

Satellites for navigation were developed in the late 1950s as a direct result of ships needing to know exactly where they were at any given time. In the middle of the ocean or out of sight of land, you cannot find out your position accurately just by looking out of the window. In recent years, satellites have been used for accurate navigation. Global Positioning System (GPS) is the first system that was primarily intended for use as a highly accurate military system. Using GPS technology these satellites can provide exact location of a person on the Earth's surface. Since then it has been adopted by a huge number of commercial and private users. Now-a-days, GPS systems are available at reasonable costs that are affordable by individuals. GPS systems used for car navigation are good example of this. They are even being incorporated into phones in a system known as A-GPS (Assisted GPS) to enable better locational accuracy.

4.3.6 Reconnaissance Satellites

Reconnaissance satellites are used to spy on other countries. They provide intelligence information on the military activities of foreign countries. These satellites can even detect missile launches or nuclear explosions in space. Reconnaissance satellites can pick up and record radio and radar transmissions while passing over a country.

There are following four types of reconnaissance satellites:

- optical-imaging satellites that have light sensors that detect missile launches and locate enemy weapons on the ground
- radar-imaging satellites which are able to observe the Earth using radar technology through cloud cover
- signals-intelligence or ferret satellites that are essentially super-sophisticated radio receivers that capture the radio and microwave transmissions emitted from any country on the Earth
- relay satellites that make military satellite communications around the globe much faster by transmitting data from spy satellites to stations on the Earth.

4.4 ORBITS AND THEIR TYPES

In the previous section, you have learned that remote sensing instruments can be placed on a variety of platforms to view and image targets. Let us now discuss about orbits. Any object that moves around the Earth has an orbit. An ***orbit*** is the path that a satellite follows as it revolves round the Earth. The plane in which a satellite always moves is called the ***orbital plane*** and the time taken for completing one orbit is called ***orbital period***.

Orbit is defined by the following three factors:

- shape of the orbit, which can be either circular or elliptical depending upon the eccentricity that gives the shape of the orbit
- altitude of the orbit which remains constant for a circular orbit but changes continuously for an elliptical orbit, and
- angle that an orbital plane makes with the equator

Depending upon the angle between the orbital plane and equator, orbits can be categorised into three types i.e. equatorial, inclined and polar orbits as shown in Fig. 4.2.

If the angle (known as *orbital inclination*) is 0° or 180° then the orbital plane lies in the equatorial plane and the orbit is called an *equatorial orbit*. When the angle is 90°, the satellite moves over the north and south poles and the orbit is called a *polar orbit*. However, an orbit with inclination close to 90° is called a *near polar orbit*. There could be different orbits having inclination between 0° or 90° which are known as *inclined orbits*.

When the satellite is moving from south to north it is called ascending pass or ascending node of the orbit. Similarly, when the satellite is moving from north to south it is called descending pass or descending node of the orbit. Most of the polar orbiting satellites acquire images during they pass from north to south (i.e. descending passes) over the sunlit hemisphere and return from south to north (ascending passes) over the night-time hemisphere.

You should also be familiar with the following two terms i.e. *Instantaneous Field of View* (IFOV) and *spatial resolution*.

The term *Instantaneous Field of View* (IFOV) characterises the sensor. It refers to projection of the detector element (i.e. one Charged-coupled Device (CCD element)) on the ground. It is also known as the 'footprint' of the detector element on the ground. IFOV is also referred as *resolution element*.

The term s*patial resolution* is used to denote the projection of the detector element (CCD) on to the ground through imaging optics from the satellite/aerial orbit.

You will learn more about resolution in the next unit.

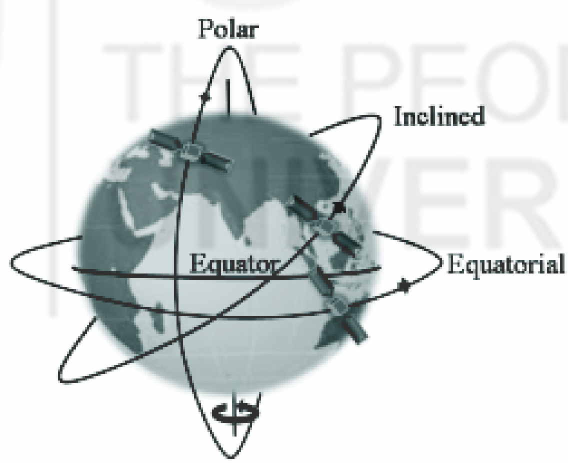


Fig. 4.2: Schematics showing three types of orbits i.e. equatorial, polar and inclined orbits

Field of View (FOV) is the total view angle of the camera, which defines the swath (Fig. 4.3). When a satellite revolves around the Earth, the sensor observes a certain portion of the Earth's surface. *Swath* or *swath width* is the area (strip of land of Earth surface) which a sensor observes during its orbital motion (Fig. 4.3). Swaths vary from one sensor to another but are generally higher for spaceborne sensors (ranging between tens and hundreds of kilometers wide) in comparison to airborne sensors. The polar orbiting satellites are able to acquire images of almost the entire Earth despite the fact that as the satellite orbits the Earth from pole to pole, its east-west position does not change. This becomes possible because of the fact that Earth is rotating from west to east beneath the satellites. The rotation of the Earth causes a steady westward shift of the swath which allows the satellite swath to cover a new area with each consecutive pass. Thus, the swath is generated by the combined action of satellite orbital motion and the Earth's rotation relative to the orbital plane and it allows complete coverage of the Earth's surface.

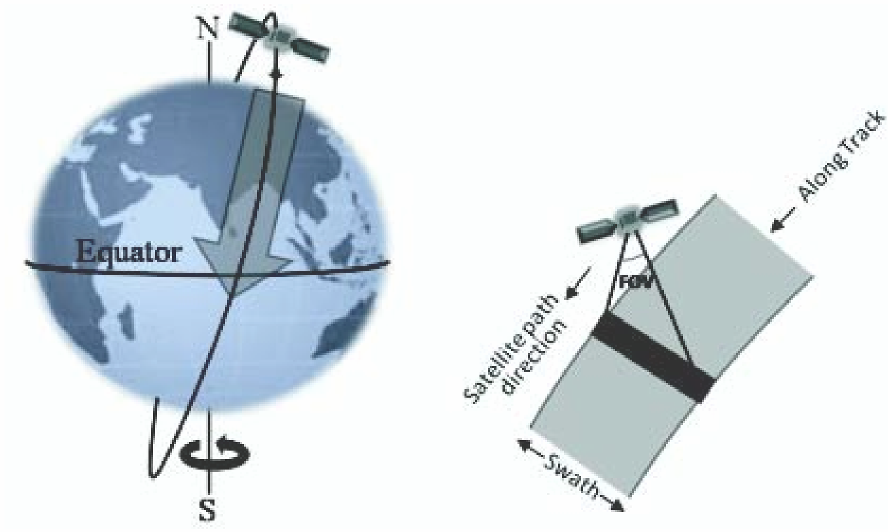


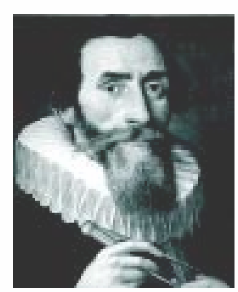
Fig. 4.3: Schematics showing the concepts of swath and Field of View (FOV). (a) Satellite imaging a strip of land (i.e. swath) on its descending pass; (b) showing relation between FOV and swath

You should note that elevation of the satellite orbit is designed in such a way that the same location will be retraced (imaged) in a period of few weeks. The time taken for a sensor to complete tracing (imaging) of almost the entire Earth before it starts tracing of the same area for a second time is known as *orbital cycle*. The exact length of time of the orbital cycle varies with each satellite.

It is also important to note that an orbit that brings the satellite over the poles or close to them has a large angle but an orbit that makes the satellite stay close to the equator has a small angle. As a consequence, the distance away from the Earth will affect the speed of the object in orbit. So, the orbit selection can vary in terms of:

- altitude above the surface of the Earth, and
- the orientation and rotation of orbits relative to the Earth.

Choice of an orbit depends upon the purpose as different orbits serve different purposes and each has its own advantages. Kepler has formulated the mathematical laws describing satellite orbits in 18th century. Based on his planets and moons motion observations, Kepler has demonstrated that satellites may be flown on elliptical orbit instead of circular orbit.



Johannes Kepler (December 27, 1571 – November 15, 1630) was a German mathematician, astronomer and astrologer. He is best known for his laws of planetary motion.

Broadly, orbits are classified into two types, i.e. closed and open orbits:

- **Closed orbits:** They can be either circular or elliptical in shape. A body on a closed orbit constantly travels around another body, such as a planet orbiting the Sun or the Moon orbiting the Earth. All planets and moons in our solar system follow this type of orbit.

- **Open orbits:** They follow mathematical shapes which are either known as a parabola or a hyperbola. Unlike circles, parabolas and hyperbolas form curves whose ends never join up.

There are different types of closed orbits used for operating various satellites. Most commonly used satellite orbits are outlined below.

- Geosynchronous Orbit
- Sunsynchronous Orbit

4.4.1 Geosynchronous Orbit

It is a west to east equatorial orbit in which a satellite is placed on the equatorial (0° latitude) orbital plane at an altitude of about 36000 km above the Earth's surface (Fig. 4.4). At this altitude satellites travel in this orbit with the same speed and direction as the Earth. A *geosynchronous orbit* is an orbit which has an orbital period that matches the Earth's sidereal rotation period. The synchronisation of rotation and orbital period means that for an observer on the surface of the Earth, the satellite appears to constantly hover over the same meridian (north-south line) on the surface, moving in a slow oscillation alternately north and south with a period of one day, so it returns to exactly the same place in the sky at exactly the same time each day.

There is a special case of a geosynchronous orbit which is known as geostationary orbit. This is a geosynchronous orbit that is circular and at zero inclination i.e. directly above the equator. As a result, the satellites remain stationary vertically above a fixed point on the Earth's surface. Hence, relative to any location on Earth, the position of the satellites remains stationary. This orbit is called *geostationary orbit* and the satellite revolving in this orbit is called a *geostationary satellite*. The geostationary satellite takes ~24 hours time (i.e. one day) to complete one orbit around the Earth, which is also the same time period for Earth's rotation. This is why to people on the ground the geostationary satellites appear to be motionless, and at a fixed position in the sky. Any sensor system on the geostationary satellites views the same area at all time. This is a much higher orbit in which satellites take a lot more energy to reach.

At this altitude satellites have a view of almost the entire of one hemisphere. Resolutions of imagery from geostationary are very coarse. It provides distorted images of the polar region with poor spatial resolution. For this reason, imaging and mapping satellites are not geosynchronous. Thus, communication and weather purposes are the most common use of geostationary orbit. Communications satellites are often given geostationary orbits, or close to geostationary, so that the satellite antennas that communicate with them do not have to move but can be pointed permanently at the fixed location in the sky where the satellite appears.

Geostationary satellites provide a large coverage which is useful for monitoring deadly local storms and tropical cyclones. Since these satellites continuously view same scene, as a consequence, these are ideal to study dynamic phenomenon, such as cyclone movement, cloud motion, etc.

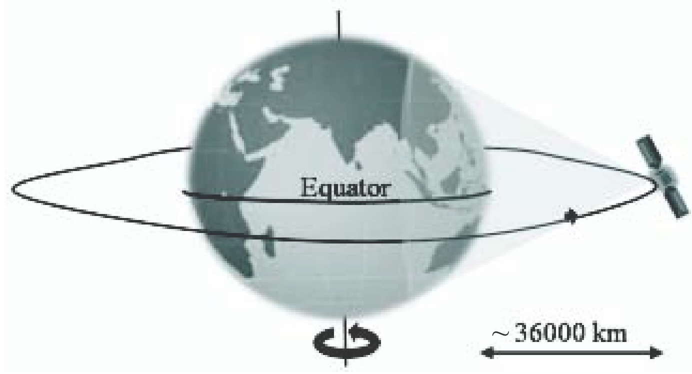


Fig. 4.4: Schematics showing the geosynchronous orbit

Advantages of geostationary orbits are the following:

- large spatial coverage (five geostationary satellites are enough to cover all of the non-polar regions of the Earth)
- one satellite can cover almost 1/3 of Earth's surface
- permanent visibility of the satellite allowing continuous telecommunications and high rate of repetition for observations
- one ground segment is enough for the satellite monitoring.

4.4.2 Sunsynchronous Orbit

Polar orbits have an inclination of 90° with respect to the equatorial plane of the Earth (Fig. 4.5). A polar orbit is a satellite orbit that passes close to the both poles of the Earth. As the name suggests, polar orbits pass over the Earth's polar regions from north to south. During a 12-hour day, a satellite in such an orbit can observe all points on the Earth. The satellite moving in a polar orbit is called a *polar satellite*. The satellites always follow the same orbits. The Earth rotates underneath and allows satellite to see virtually every part of the Earth. It takes approximately 90 minutes for the satellite to complete one orbit. These satellites pass over the equator at the same solar time every single day, which allows it to collect data consistently. The orbits are low altitude orbits between 200 and 1000 km above the earth. The satellite offers the best views of the planet, particularly of areas that are often difficult to cover.

Polar orbit satellites are used for reconnaissance and Earth observation. They are also used for measuring ozone concentrations in the stratosphere or measuring temperatures in the atmosphere. Polar orbits are also sometimes used for weather satellites.

Fig. 4.5: Schematics showing the polar orbit

Ideally, all satellite images should be acquired under uniform illumination condition, so that features present in images of same area taken on different dates show the changes in ground conditions rather than changes in conditions of observation. However, in reality, satellite images of different dates vary because of differences in latitude, time of day and season resulting into different illumination conditions.

When the orbits are designed in such as way that the satellite's orientation is fixed relative to the Sun throughout the year such orbits are called *sunsynchronous orbits*. These orbits are designed to remove one source of variation in illumination which is caused by differences in time of day. Satellite in sunsynchronous orbit passes over a given part of the Earth at roughly the same local time of day (though not necessarily every day). In other words, whenever the satellite observes a given ground scene, the Sun is always in the same location in the sky. Since there are 365 days in a year and 360° in a circle, it means that the satellite in this orbit has to shift its orbit by approximately 1° per day. The satellite orbiting in this orbit is called a *sunsynchronous satellite* (Fig. 4.6). Sunsynchronous satellite flies at an altitude between 700 and 800 km with an orbital period between 90 and 110 minutes.

Satellites in sunsynchronous orbits pass from north to south poles on the sunlit side (the descending node) and from south to north on the shadowed side (the ascending node). Sensors that depend upon the solar radiation acquire images only during their descending pass but other sensors can acquire data independently during both the passes. Sunsynchronous orbits are particularly useful for missions that acquire images of the Earth because shadows from objects at a given location on the Earth's surface are always cast from the same angle. This simplifies the comparison of images taken on different days to detect changes. Satellites in this orbit are often placed at low altitudes (700 to 800 km) so that they provide complete coverage of the Earth's surface at least once per day.

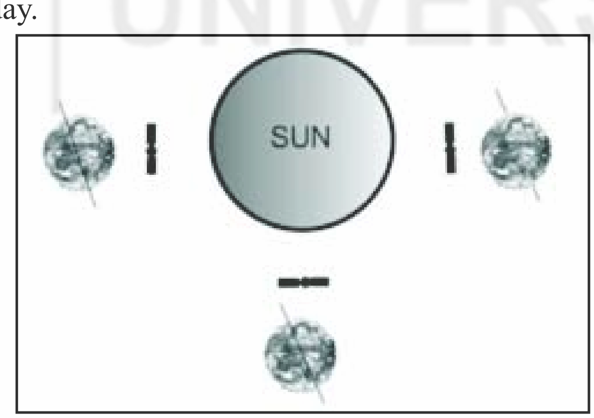


Fig. 4.6: Schematics showing the sunsynchronous orbit

Remote sensing and meteorological satellites are placed in the sun-synchronous orbit. Orbview, Quickbird, IKONOS, SPOT, Landsat, ERS, RADARSAT, etc. are examples of the satellites orbiting in sunsynchronous orbit.

Dawn-to-dusk orbit is a special case of sunsynchronous orbit, in which the orbital plane of the satellite coincides with the plane that divides the half of the Earth that is illuminated by the Sun from the half that is dark. If the plane were aligned slightly differently, the satellite would spend half of its time in full sunlight and half in shadow but a dawn-to-dusk orbit allows the satellite to always have its solar panels illuminated by the Sun. For example, the Canadian Radarsat Earth observation satellites use such a dawn-to-dusk orbit to keep their solar panels facing the Sun constantly, so they can rely primarily on solar power rather than batteries.

As you know the Earth is not a perfect sphere. The bulging near the equator causes additional gravitational forces to act on the satellite. This causes satellite orbit to either proceed or recede. These orbits are used for satellites that need a constant amount of sunlight. Satellites that take pictures of the Earth would work best with bright sunlight, while those which measure longwave radiation would work best in complete darkness. Generally, these orbits are used for Earth observation, solar study, weather forecasting and reconnaissance.

4.5 SENSOR SYSTEM

In the previous three sections you have studied about platforms and orbits of satellites. Now we will discuss about the instrument, i.e. sensors systems which is carried by satellites. The sensor systems are simply the eyes of the satellites that view and record the scene. Sensors are the special instruments mounted on the platforms (aeroplane or satellite) usually having sophisticated lenses with filter coatings, to focus the area to be observed at a specific region of EMS. Solar radiation is the main source of EMR and is a combination of several wavelengths such as gamma ray, x-ray, visible, infrared, thermal and microwaves. Sensor systems mainly operate in the visible, infrared, thermal and microwave regions of EMR. Sensors are characterised by spatial, spectral and radiometric performance as described in the next unit.

The first issue to be considered in selecting the sensor is the scale. Terrestrial and airborne sensors have high spatial resolution but sensors mounted on satellite, meant for acquiring synoptic coverage have relatively coarse spatial resolution. Selection of appropriate sensor system for the remote sensing satellite will also depend on the criteria to be addressed for using highly localised and refined or more regional and coarse sensor systems.

Sensor systems are classified as imaging and non-imaging sensors based on the type of output they provide. Imaging sensors measure the emitted / reflected intensity of EMR and provide image of the ground as output (e.g. photographic camera) whereas non-imaging sensors measures the intensity of radiation but does not provide any image and the observations are in the form of some numerical data (e.g. Gravimeter). We will focus here on the imaging sensor systems. As shown in the Fig. 4.7, sensor systems can be broadly classified as passive or active systems based on the source of EMR:

- **Passive Sensors**

  They detect the reflected or emitted EMR from natural sources. The useful wave bands are mostly in the visible and infrared region for passive remote sensing detectors.

- **Active Sensors**

  They detect the reflected or emitted radiation from the objects which are irradiated from artificially generated energy sources, such as RADAR and

LIDAR. The active sensor detectors are used in the radar and microwave regions.

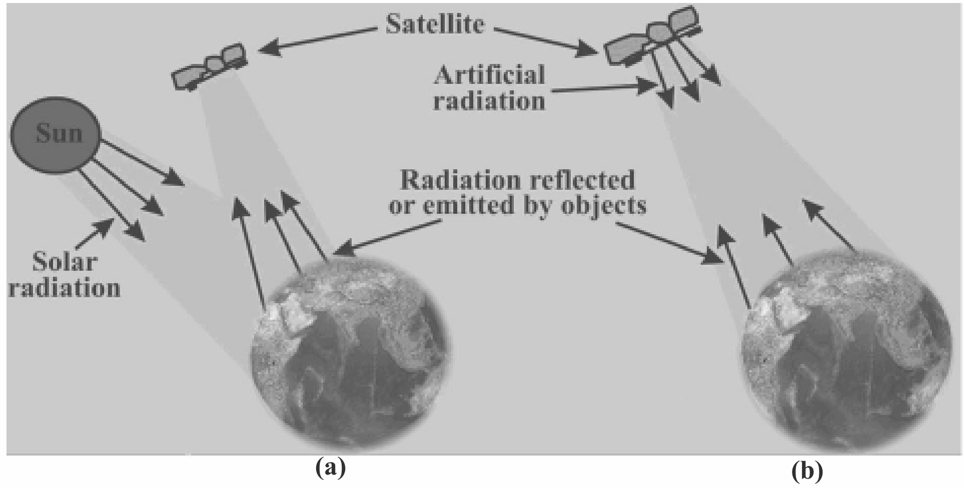


Fig. 4.7: Schematics showing the functional mechanism of (a) passive and (b) active sensors

Broadly, all the imaging sensors systems are classified based on technical components of the system and the capability of the detection by which the energy reflected by the terrain features is recorded (Fig. 4.8).

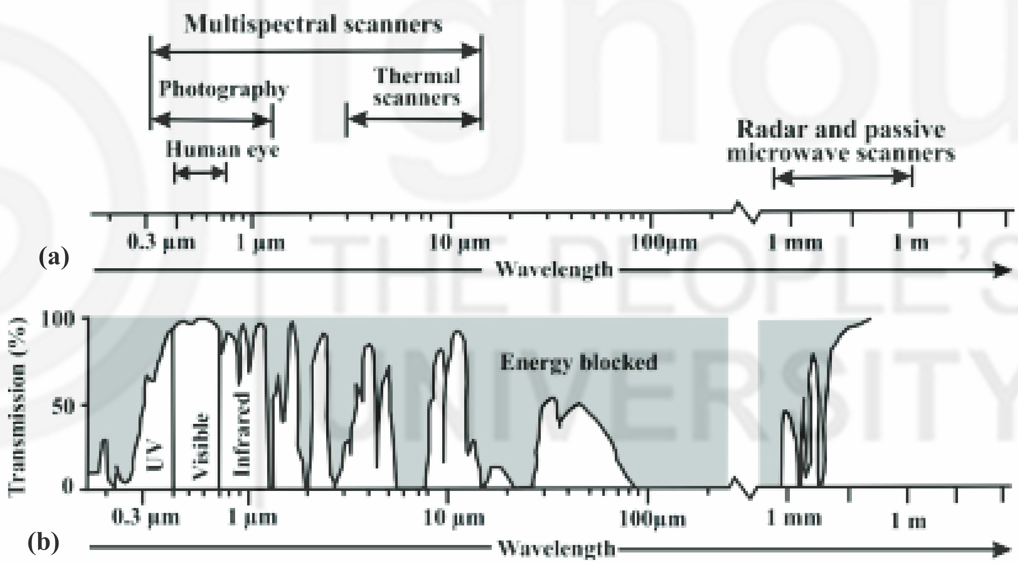


Fig. 4.8: Atmospheric transmission and the wavebands of common remote sensing systems; (a) Remote sensing scanners, and (b) atmospheric transmittance

The active and passive sensors can be further classified as shown in Table 4.1.

Table 4.1: Types of remote sensing sensors

Types of sensors	Subtypes based on the wavelength region of EMS detected	Subtypes based on sensing mechanism	Examples
Passive sensors	Optical-infrared (multispectral) sensors	Photographic and television cameras	MKF-6M; S065; Bhaskara-1, 2; Landsat RBV.
		Opto-mechanical scanner	Landsat MSS and TM, INSAT, VHRR.
		Push-broom scanner	IRS-LISS, WiFS SPOT HRV

	Thermal sensors	Thermal infrared scanner	Landsat TM, TIMS, MODIS, ASTER, AVHRR
	Microwave sensors	Scanning microwave radiometer	Oceansat-1 MSMR (Multi-channel scanning microwave)
Active sensors	Optical-infrared sensors	LIDAR	Leica ALS70 Airborne LIDAR Sensor
	Microwave sensors	RADAR	RADARSAT SAR
		Scatterometer/ Altimeter	Seasat

In this unit we will further discuss about the sensor systems under the following headings:

- Multispectral imaging sensor systems
- Thermal remote sensing systems
- Microwave radar sensing system

4.5.1 Multispectral Imaging Sensor Systems

Focal plane is the plane that is perpendicular to the axis of a lens or mirror and passes through the focal point.

The multispectral imaging sensors include photographic and scanning systems. The photographic system is an imaging system in which cameras are used. In the scanning system, scanners along with filters for various wavelength regions are used. In some cases both photographic and scanning systems are used in combination.

In the photographic system, different parts of the spectrum are sensed with different film-filter combinations and images are formed directly on to a film. In the opto-mechanical (scanning system) sensors, the optical image is first converted into an electrical signal (video data) and later processed to record or transmit the data. But the photographic system suffers from one major defect of considerable distortion at the edges. This is due to large lens opening.

- **Analog (Photographic) Systems**

  Photographic cameras are the oldest and most widely used remote sensing sensor especially in aerial photography. Cameras, belong to framing system, have been successfully used as the remote sensors from aircraft, balloons and manned and unmanned spacecraft. Camera systems are passive optical sensors that use a lens or system of lenses to form an image at the focal plane where an image is sharply defined. The images are recorded on the photographic films which are sensitive to light from 0.3 ìm to 0.9 ìm in wavelength covering the ultraviolet, visible, and near-infrared. The analog or photographic film is generally composed of single layer of silver halide emulsion (black and white or panchromatic) or triples layers of yellow, magenta and cyan colours for colour photographs. When the photographic film is exposed, over a particular area the molecules of the film's emulsions react with the radiation emitting from that particular area. And the film developed produces a black and white or colour representation of the continuous range of light intensity as evidenced across that particular area.

Field-of-view (FOV) defines the width on the ground (i.e. swath) which is captured in an image.

Refer to Unit 5: Image Resolution, for more details on spatial and spectral resolution.

Detector is a device that produces an output signal depending upon the amount of radiation falling on its active area. It converts electromagnetic energy into electrical signal; hence called electro-optical detectors. Each detector has a spectral region for which only it can be used.

Instantaneous field-of-view (IFOV) is a patch of the landscape visible to a detector at any one time. IFOV determines the spatial resolution.

Box-Framing systems instantaneously measure radiation coming from the entire scene at once and record an image of an area. Cameras, eye and vidicons are common examples of framing systems. The size of the scene that is framed depends on the apertures and optics of the system that define the field of view.

Generally, the panchromatic and colour films are sensitive to the light in the visible region. But the photographic films developed specially for remote sensing analysis are sensitive to reflected-IR light, which are used extensively for vegetative mapping analysis.

Earlier, photographic imageries were interpreted visually. Now-a-days the scanning technology made it easier to convert whole analog photographs to digital images. The scanned photographic imageries take advantage of feature enhancement and extraction facilities available within most image processing software packages. Nevertheless, the spatial and spectral resolution of the original photograph cannot be enhanced by scanning.

- **Scanning Systems**

Photographic system uses chemical reactions on the surface of a light sensitive film to detect energy variations within a scene and the film acts as both detecting and recording medium whereas the opto-mechanical sensor generates an electrical signal that corresponds to the energy variations in the original scene and the signals are recorded onto some magnetic medium.

The scanning systems use an electrical sensor called detector that records the brightness of the small scene of the terrain within its instantaneous field-of-view (IFOV) to produce an image. The brightness (electrical) signals which are recorded by the detector vary continuously in proportion as the optics of the sensors and mirrors sweep the IFOV over the landscape. This signal is amplified, recorded in the magnetic tape and then converted to digital form to produce an image. In this way an image is produced from a series of adjacent cells or picture elements (pixels). The scanning system is able to record the brightness of the entire terrain by sweeping the detector rapidly across the terrain.

Multispectral scanner systems can sense from 0.3 µm to 14 µm and further they can sense in very narrow bands. According to lens theory, the distortions can be minimised and resolution be improved considerably by using a narrow beam of light and this can be achieved by a system called *scanning system.*

The multispectral scanning systems sweep the IFOV of the detector across the terrain in a series of parallel scan lines. There are four common types of scanning modes for the scanning system:

a) across-track scanning system

b) along-track scanning system

c) side looking or oblique scanning system (Radar)

d) spin scanning system

a) Across-Track Scanners

This type of scanning system employs a faceted mirror that is rotated by an electric motor in which horizontal axis of rotation aligned parallel with the direction of flight. The mirror scans the terrain in a pattern of parallel scan lines that are right angles to the direction of the airborne platform as shown in Fig. 4.9 (a). Energy reflected or radiated from the ground is reached onto the detector by the mirrors. This kind of scanner systems is also called as *whisk broom scanner system*. The factors affecting the strength of sensor signal produced by a detector are the energy flux, altitude of the sensor, spectral bandwidth of the detector, IFOV and dwell time. The across-track scanners have short dwell time that results in detector receiving less energy and creating a weaker signal. Examples of across-track scanners are Multispectral Scanner (MSS) and Thematic Mapper (TM) of Landsat series of satellites.

Angular field of view is that portion of the mirror sweep that is recorded as scan line and measured in degree.

Ground resolution cell is an area of the ground that is covered by IFOV of a detector.

Dwell time is the time taken by the detector IFOV to sweep across a ground resolution cell. The longer dwell time allows more energy to strike on the detector to create a stronger signal.

Ground swath is the width of the strip of the terrain that is recorded by the scanner.

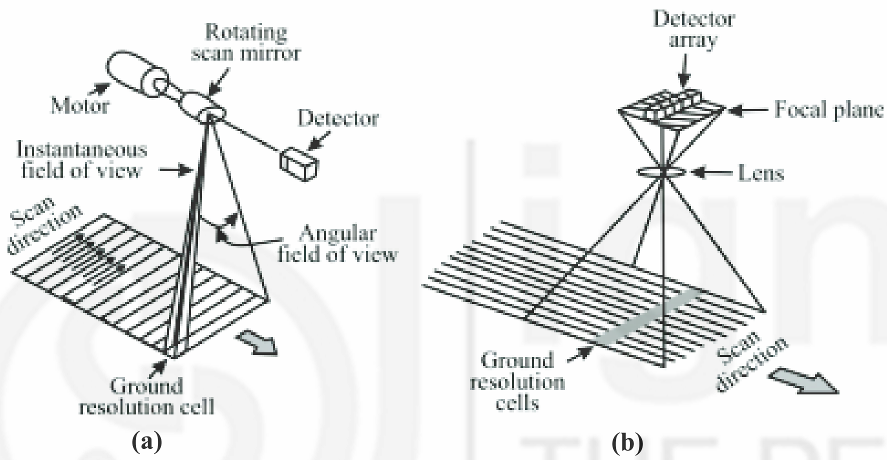


Fig. 4.9: Schematics showing sensor's scanning modes. (a) across-track mode; and (b) along-track mode (redrawn from Sabins, 1986)

- **Landsat Multispectral Scanner (MSS):** It was the primary sensor system for the Landsats 1-3 and 4-5. This sensor had four spectral bands ranging from 0.5 to 1.1 µm in the electromagnetic spectrum that record reflected radiation from the Earth's surface. These bands are green (0.5 to 0.6 µm), red (0.6 to 0.7 µm), and near-infrared (0.7 to 0.8 and 0.8 to 1.1 µm). In addition, the subsequent Landsat MSS contained an additional thermal infrared band of electromagnetic spectrum. MSS had an oscillating mirror that scans a 185 km wide ground swath. MSS also had a spectrometer and six detectors for each spectral band. The spectrometer separates the solar radiation reflected from the landscape into four different spectral bands or wavelengths whereas detectors record six scan lines during every sweep of the scan mirror. Later, the energy sensed by the detectors is converted into electrical signals for recording and transmission as an image data.

Landsat data are widely used for detecting and monitoring Earth's resources. Among the four bands of MSS, band 1 is used to detect green reflectance from healthy vegetation, and band 2 for detecting chlorophyll absorption in vegetation. MSS bands 3 and 4 are ideal for recording near-infrared reflectance peaks in healthy green vegetation and for detecting water-land interfaces.

- **Thematic Mapper:** Thematic Mapper (TM) is an advanced second generation of MSS first deployed on Landsat-4 and 5. Its design offered spatial, radiometric, and geometric improvements over the MSS systems. The design of the TM was more complicated than the MSS. TM is an across-track scanner similar to MSS with an oscillating scan mirror and arrays of detectors. TM provides data which are scanned simultaneously in seven narrow spectral bands covering visible (blue- 0.45 - 0.52 ìm, green - 0.52 - 0.60 ìm, and red - 0.63 - 0.69 ìm), near infrared (0.76 - 0.90 ìm), middle infrared (1.55 - 1.75 ìm and 2.08 - 2.35 ìm) and thermal infrared (10.4 - 12.5 ìm). TM provides data with a 30 m resolution in the visible, near infrared and middle infrared and 120 m resolution in the thermal infrared regions of EMR.

b) Along-Track Scanning System

Along-track scanners record multiband image data along a swath beneath the aircraft (Fig. 4.9b). As the aircraft advances in the forward direction, the scanner scans the Earth with respect to the designed swath to build a two dimensional images by recording successive scan lines that are oriented at right angles to the direction of aircraft. In this system, detectors are placed in a linear array in the focal plane of the image formed by a lens system. This system is also called as a *push broom system* because the array of the detectors that record terrain brightness along a line of pixels are effectively pushed like a broom along the orbital path of the aircraft. The along track scanners have long dwell time in which the detectors provide fine spatial and higher spectral resolutions.

The difference between along-track system and across track system is that the linear arrays of detectors are used in push broom sensor instead of a rotating mirror. Example of an along-track scanner is SPOT-High Resolution Visible (HRV) camera and Linear Imaging Self Scanning Sensors (LISS) of Indian remote sensing (IRS).

- **Linear Imaging Self Scanning Sensor:** Linear imaging self scanning (LISS) is a sensor system designed by ISRO for Indian remote sensing satellites. In fact, LISS is a multispectral camera systems in which each camera system contains four imaging lens assemblies one for each band followed by a linear charge coupled devices (CCD) array. The optics focuses a strip of landscape in the across track direction on to the sensor array. The images obtained from each detector are stored and later shifted out to get video signals. It operates in four bands which are B1 (0.45-0.52 µm), B2 (0.52-0.59 µm), B3 (0.62-0.68 µm) and B4 (0.77-0.86 µm) in the visible and near infrared wavelength of electromagnetic region. At present, there are four versions of LISS and each version has its own specifications.

LISS-III is a medium resolution multispectral camera almost similar to the LISS-I. In LISS-III camera, the band 1 is replaced by short-wave infrared (SWIR) band B5 (1.55-1.70 µm). As a consequence, it provides images in visible as well as SWIR bands. The spatial resolution and ground swath of LISS-III is 23.5 m and 141 km, respectively, in all the four bands. LISS-IV is a high resolution multispectral camera operating in three spectral bands (B2, B3, B4). LISS-IV camera operates in both mono (any single band out of B1, B2 and B3) and multispectral mode. The ground swath of LISS-IV is 23.9 km and 70 km for multispectral and mono mode, respectively. LISS-IV camera can be tilted up to ± 26° in the across track direction thereby providing a revisit period of 5 days.

c) Side Looking or Oblique Scanning Systems (Radar)

Side looking scanning system is an active scanning system, e.g. radar. This system itself generates EMR, then illuminates the terrain and detects the energy (radar pulses) returning back from the terrain and records it as an image. Therefore, radar imagery is received by collecting and measuring the reflections of pulses sent out from radar equipped in the aircraft and satellites. Side Looking Airborne Radar (SLAR) is one of the common types of remote sensing techniques used for obtaining radar images of the terrain. The main components of SLAR include antenna, duplexer, transmitter, receiver, pulse-generating device and cathode ray tube (Fig. 4.10).

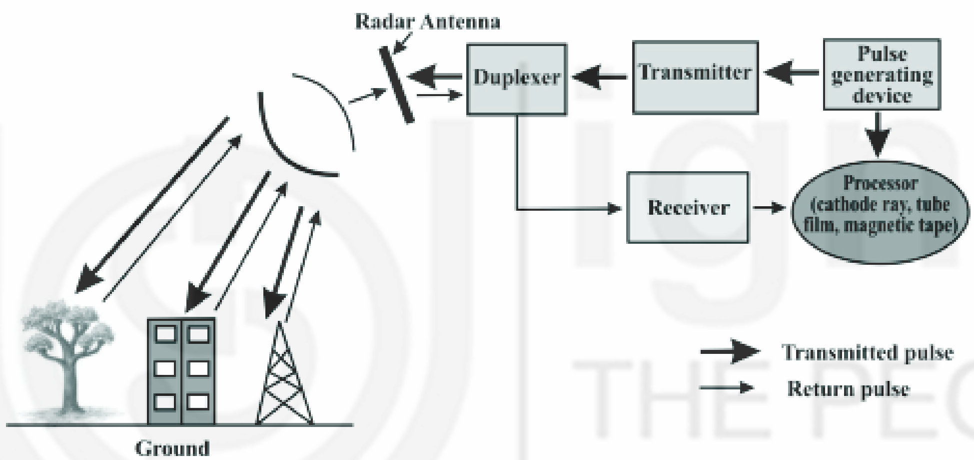


Fig. 4.10: Schematics showing components of a SLAR

In this system, the radar antenna sends the radar pulse to the ground and receives the radar return from the ground. Duplexer is an electronic switch and its main function includes the prevention of interference between radar return and transmitted beams. Receiver records the timing and intensity of radar return and also amplifies the weak pulses received by the antenna. This helps to identify features of the terrain appeared on an image. Finally, radar return may be displayed on a cathode ray tube and get recorded on film or in the magnetic tapes. Overall, an image created is a function of time and strength of the radar pulse that is returned from the Earth's objects. The resolution of radar systems can be determined by the radar beam width of the microwave pulse generated by the system. It is calculated by the equation given below:

Resolution (m) = range (km) × wavelength (cm) / antenna aperture (m)

The range direction is the direction of the pulses of the microwave transmitted from the antenna to illuminate the strips of the landscape in the look direction. While look direction is perpendicular to the azimuth or aircraft flight direction. Range direction may be near or far range. In near range, the transmitted pulses lie close to the aircraft flight path and hence have short travel time but in far range, pulses are very far away from the aircraft and have long travel time (Fig. 4.11).

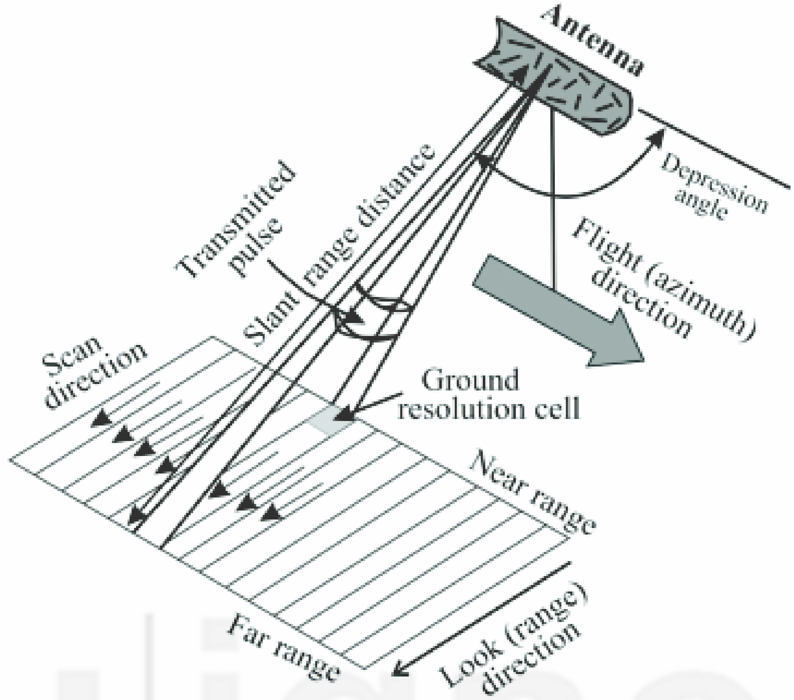


Fig. 4.11: Side looking scanning system (modified from Sabins, 1986)

4.5.2 Thermal Remote Sensing System

Thermal scanners belong to the electro-optical scanning systems. These scanners sense the thermal infrared portion of the EMS. Thermal scanners do not record the true internal temperature of objects but record the pattern of radiant temperature variation of the objects. As a consequence, they sense energy emitted rather than reflected from objects, therefore, thermal scanners can operate day or night. Thermal scanners use photo detectors to detect emitted thermal radiation. The detectors are cooled to temperatures close to absolute zero in order to limit their own thermal emissions.

Thermal infrared scanners scan the terrain in the across-track mode. A thermal airborne infrared scanner consists of an electric motor and a rotating shaft which is oriented parallel to the aircraft flight direction (Fig. 4.12). Both these instruments are mounted in the aircrft. The scan mirror which is inclined at 45º mounted on the one end of the shaft sweeps the terrain at a right angle to the fight path. This scan mirror also detects the infrared energy emitted from the terrain. Later, it sends the energy to focusing mirrors where the energy get detected by the detector. The detector converts the emitted energy into an electrical signal. The signal varies in proportion according to the intensity of emitted infrared radiation. Detector is normally placed by a vacuum bottle filled with liquid nitrogen. A second mirror known as recorder mirror placed at another end of the shaft rotates synchronously with the scan mirror and sweeps the image of the modulated light source across a strip of recording film.

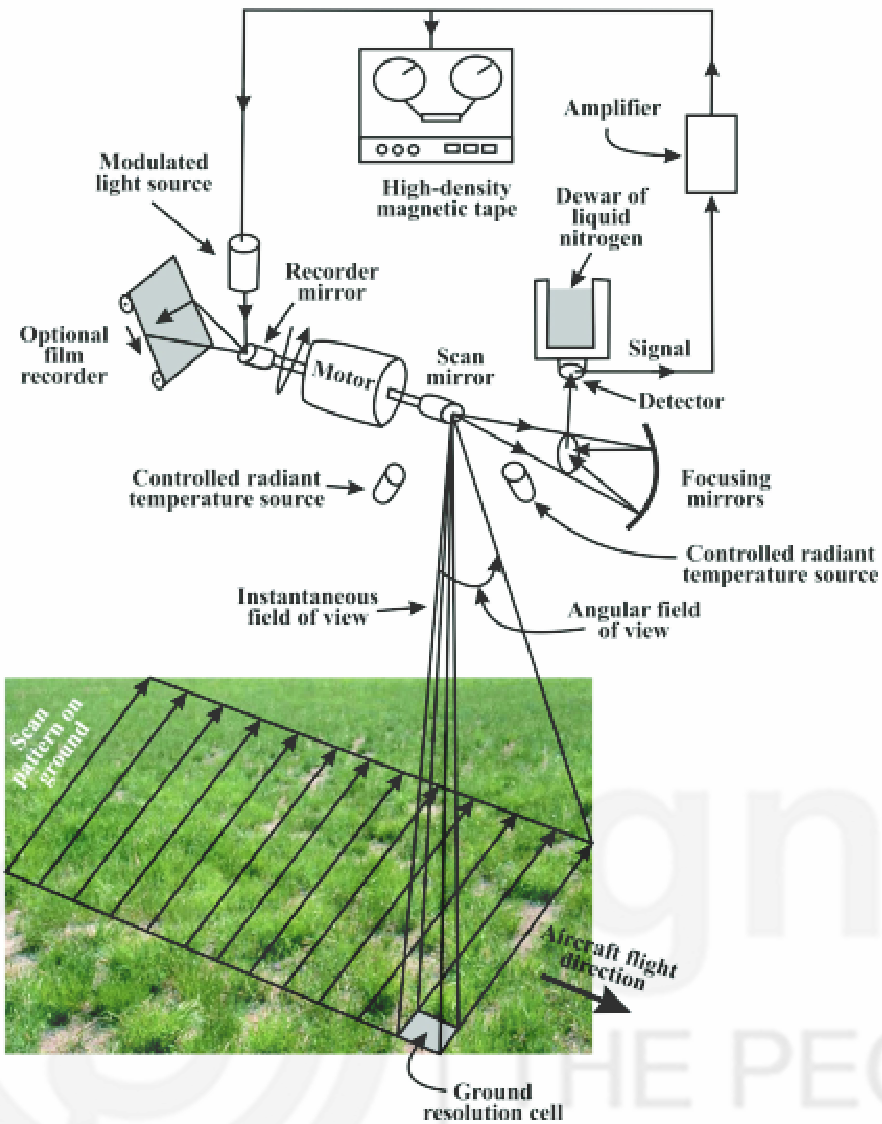


Fig. 4.12 : Schematic representation of thermal infrared scanner (modified from Sabins, 1986)

Heat Capacity Mapping Mission (HCMM) detected radiation in two bands which were visible/near- infrared (0.5-1.1 ì m) and thermal infrared (10.5-12.5 ì m). The Landsat-3 MSS and TM both included thermal bands of EM spectrum. Since Landsat TM has seven spectral bands hence provides more radiometric information than Landsat MSS. *Thermal Infrared Multispectral Scanner* (TIMS) which was developed by the Jet Propulsion Laboratory of NASA collects data with six thermal bands ranging from 8.2 to 12.2 ìm. *Moderate Resolution Imaging Spectroradiometer* (MODIS) was launched in 1999 with 36 spectral bands and spatial resolution ranging from 250-1,000 m. *Advanced Spaceborne Thermal Emission and Reflection Radiometer* (ASTER) has 14 spectral bands and scans the terrain in visible/NIR, SWIR and thermal infrared with spatial resolutions 15 m, 30 m, and 90 m, respectively. *Advanced Very High Resolution Radiometer* (AVHRR) of the National Oceanic and Atmospheric Administration (NOAA) has thermal infrared scanners in the two thermal atmospheric windows (3.55-3.93 ìm and 10.5-11.5 ìm) with a ground resolution of 1.1 km to measure top cloud temperature and seawater temperatures.

Thermal sensors essentially measure the surface temperature and thermal properties of objects. Hence, thermal imagery has diverse application in the field of geology (geologic mapping of the formation with different thermal properties and for locating underground coal mine fires), soil science (soil mapping, and determination of moisture conditions), and forestry (studying evapo-transpiration from vegetation, delineating the extent of active forest fires) and for the study urban land surface temperature (detection of heat losses from houses, buildings and factories).

4.5.3 Microwave Imaging System

Side Looking Airborne Radar (SLAR) is an airborne radar, viewing at right angles to the axis of the vehicle, which produces a presentation of terrain or moving targets. The platform (aircraft or satellite) of an SLAR travels forward in the flight direction with the nadir directly beneath the platform.

The microwave region of the EM spectrum includes wavelengths from 1mm to 1 m. The advantage of microwave remote sensing is that microwaves are capable of penetrating the atmosphere when it is with conditions like cloud cover, snow and smoke. They also have the capacity of sensing in day or night. Microwave imaging systems can be classified into two categories namely, a) active and b) passive microwave remote sensing.

Active Microwave Remote Sensing

Active microwave sensing systems are of two types and they are imaging sensors and non-imaging sensors. Most imaging sensors or imaging radars used for remote sensing e.g. SLAR. These imaging radars are again divided into real aperture and synthetic aperture systems.

Passive Microwave Remote Sensing

Non-imaging remote sensing radars are either scatterometers or altimeters. Passive microwave sensors, called *radiometers*, measures the natural emitted energy from the Earth's surface. The suitable antenna collects the emitted energy and transforms it as a signal. It is represented as an equivalent temperature, i.e. the temperature of a black body source which produces the same amount of signal in bandwidth of the system. Passive remote sensing is possible if the radiometer is used in a scanning mode just like the optical scanner.

Check Your Progress II

Spend 5 mins

1) Write down the difference between active and passive sensors.

....

....

....

....

....

4.6 SUMMARY

In this unit, you have studied:

- What is platform and its types.
- What is orbit and its types.
- What is sensor and its types.

- There are varieties of platforms such as satellites, space stations, aircraft, etc., which carry imaging device (sensors) used for remote sensing purposes.
- There are many applications for satellites in today's world including military and civilian Earth observation satellites, communication satellites, navigation satellites, weather satellites, etc.
- Satellite remote sensing can significantly enhance the information available from traditional data sources because it can provide synoptic view of large portions of the Earth.
- Satellites can operate in several types of Earth orbit and they have several unique characteristics which make them particularly useful for remote sensing of the Earth's surface.
- There are three main sensor systems, multispectral, thermal and microwave systems.

4.7 UNIT END QUESTIONS

Spend 30 mins

1) Define remote sensing platforms and describe ground based, aerial and space borne platforms.
2) What does the term orbit mean and what is the difference between open and closed orbits?
3) How high geosynchronous satellite is above the centre of the Earth?
4) Describe different types of sensor systems.

4.8 REFERENCES

- http://ccrs.nrcan.gc.ca/resource/tutor/fundam/chapter2/02_e.php.
- http://rst.gsfc.nasa.gov/Intro/Part2_1x.html.
- Sabins, F. F. (1986), *Remote Sensing. Principles and Interpretation*, 2nd Ed., Oxford: W. H. Freeman & Co., New York, 449 p.

All the above websites were retrieved on April 14, 2011.

4.9 FURTHER/SUGGESTED READING

- Campbell, J.B. (2002), *Introduction to Remote Sensing*, 4th Ed., The Guilford Press, New York, 625p.
- Joseph, G. (2005), *Fundamentals of Remote Sensing*, 2nd Ed., University Press (India) Pvt. Ltd, 486p.

4.10 ANSWERS

Check Your Progress I

1) Platforms used in remote sensing are: terrestrial, aerial and space platforms.
2) Aircraft have several useful advantages as platforms for remote sensing

systems such as

i) Aircraft can fly at relatively low altitudes

ii) They can be deployed wherever and whenever weather conditions are favourable

Check Your Progress II

1) Passive sensors can only be used to detect energy when the naturally occurring energy is available and for all reflected energy, this can only take place during the time when the sun is illuminating the Earth. On the other hand, active sensors provide their own source for illumination.

Unit End Questions

1) Platforms are called the carriers for remote sensing devices, from which observations are made.

- Terrestrial platforms range from simple tripods to booms and cranes and towers.
- Airborne platforms (including airplanes, helicopters, ballons and even rockets) are capable of operating over a wide range of altitude.
- Spaceborne platforms are either short duration, such as the space shuttle, or long duration, such as the Earth resource monitoring and meteorological satellites.

2) An orbit is the path that a satellite follows as it revolves around the Earth.

- **Closed orbits:** Closed orbits are can be either circular or elliptical (oval) in shape. A body on a closed orbit constantly travels around another body, such as a planet orbiting the Sun or the Moon orbiting the Earth.
- **Open Orbits:** An open orbit follows a mathematical shape: either one known as a parabola or another called a hyperbola.

3) Geosynchronous satellite is a much higher orbit and the altitude is ~36000 km above the centre of the Earth.

4) Different types of sensor systems are multispectral imaging sensor systems, thermal remote sensing systems and microwave radar sensing system.

Hint: You can describe them as given in section 4.5.

UNIT 5 IMAGE RESOLUTIONS

Structure

5.1 INTRODUCTION

In the previous unit you have studied about remote sensing platforms and also the sensors, which are used to record the ground features. Utility and importance of any remote sensing data depend on its capability. Thus, image resolution refers to the ability of a remote sensing system to record and display the finer details, including the quality of data. One of the important characteristics of remote sensing system is their capability to capture details of the ground features. These details are broadly referred to as resolution, which can be described in terms of time, space, spectral and radiometry. *Resolution* of a sensor system is its capability to discriminate two closely spaced objects from each other. In this unit, you will study about the resolution and its types.

Objectives

After reading this unit, you should be able to:

- discuss the basic concepts and importance of image resolution in remote sensing;
- describe the types of image resolution;
- explain resolution in microwave remote sensing; and
- discuss the relationship between different types of resolution.

5.2 WHAT IS IMAGE RESOLUTION?

The term image resolution is applied to digital images, film images, and other types of images and it describes the details that an image holds. Resolution can be broadly defined as ability of a remote sensor to capture and display details of the ground features. In other words, resolution refers to the level of detail to which a ground feature can be described and mapped. Resolution varies from sensor to sensor. Resolution is broadly described as coarse and fine. Data having coarse resolution have coarser information whereas data with fine resolution provide finer details. Resolution characteristics of remote sensing data determine its application potential because data of different resolutions provide different levels of details and hence are useful for mapping particular features at a specific mapping scale.

The image resolution also depends on the character of the scene that has been imaged, apart from atmospheric conditions, illumination and experience and ability of an image interpreter. Finer details can be seen in high resolution image. On the other hand a coarse or low resolution image is one with large resolution size i.e., only coarse features can be observed in the image (Fig. 5.1).

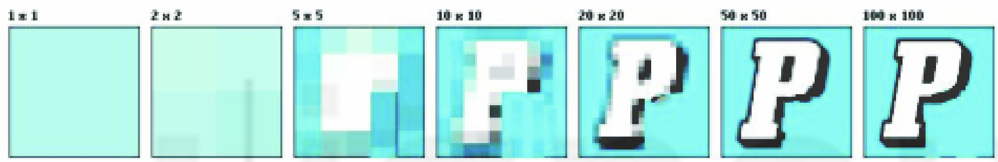


Fig. 5.1: Schematics explaining concept of resolution. How close can two points be before you cannot distinguish them?

5.3 TYPES OF IMAGE RESOLUTION

Image resolution can be measured in various ways like spatial, spectral, temporal and radiometric. Based on these parameters image resolution is categorised into following four types:

- spatial resolution – it refers to variations in the reflectance/emittance determined by the shape, size and texture of the target
- spectral resolution – it infers changes in the reflectance or emittance as a function of wavelength
- temporal resolution – it involves diurnal and/or seasonal changes in reflectance or emittance and
- radiometric resolution – it includes changes in the polarisation of the radiation reflected or emitted by an object.

We will discuss in detail about each of these types of resolution.

5.3.1 Spatial Resolution

There are different definitions of spatial resolution but in a general and practical sense, it can be referred to as the size of each pixel. It is commonly measured in units of distance, i.e. cm or m. In other words, spatial resolution is a measure of the sensor's ability to capture closely spaced objects on the ground and their discrimination as separate objects. Spatial resolution of a data depends on altitude of the platform used to record the data and sensor parameters. Relationship of spatial resolution with altitude can be understood with the following example. You can compare an astronaut on-board a space shuttle looking at the Earth to what he/she can see from an airplane. The astronaut might see a whole province or country at a single glance but will not be able to distinguish individual houses. However, he/she will be able to see individual houses or vehicles while flying over a city or town. By comparing these two instances you will have better understanding of the concept of spatial resolution. This can be further elaborated by considering an example shown in Fig. 5.2.

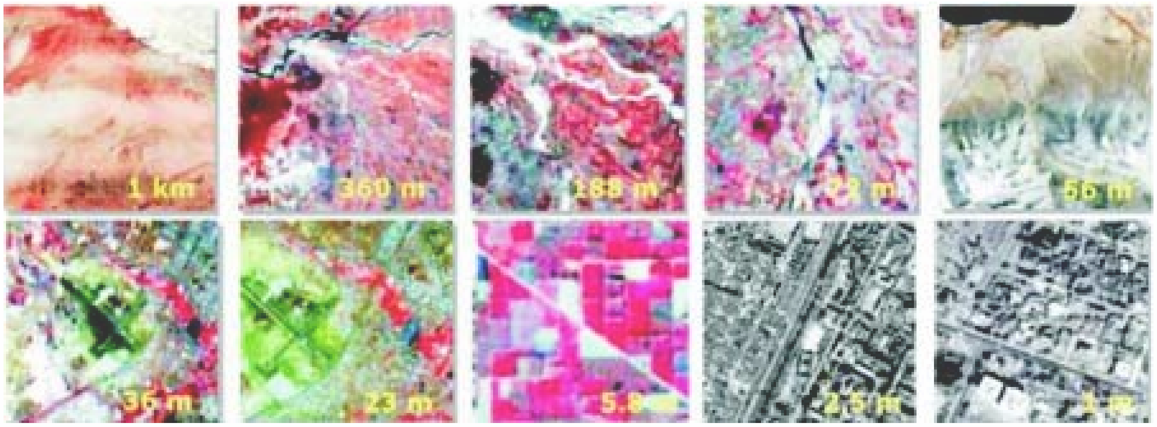


Fig. 5.2: Spatial variations of remote sensing data. Note the variations in resolution from 1 km till 1 m, in the series of photographs. The photograph taken from 1 km shows lesser details as compared to that at 1m (source: Navalgund et. al, 2007)

Suppose you are looking at a forested hillside from a certain distance. What you see is the presence of the continuous forest; however from a great distance you do not see individual trees. As you go closer, eventually the trees, which may differ in size, shape, and species, become distinct as individuals. As you draw much nearer, you start to see individual leaves (Fig. 5.3). You can carry this even further, through leaf macro-structure, then recognition of cells, and with further higher spatial resolutions individual constituent atoms and finally subatomic components can be done.

Fig. 5 3: Understanding concept of spatial resolution

IFOV is a measure of the area on the Earth surface viewed by a single detector on a sensor system from a given altitude at a given moment in time. It may be described as the angle viewed (è) or the widths on the ground (AB) of the area viewed (Fig. 5.4). It is important for you to note that AB is the diameter of the circle but radiance recorded from the area is displayed as a square pixel in an image.

The details of features in an image are dependent on the spatial resolution of the sensor and refer to the size of the smallest possible feature that can be detected. Spatial resolution depends primarily on the Instantaneous Field of View (IFOV) (Fig. 5.4A) of the sensors which refers to the size of the smallest possible feature that can be detected by each sampling unit of the sensor. Usually, people think of resolution as spatial resolution, i.e. the fineness of the spatial detail visible in an image.

The most commonly quoted quantity of the IFOV is the angle subtended by the geometrical projection of single detector element to the Earth's surface.

Remote sensing instrument is located on a sub-orbital or satellite platform, where è of IFOV, is the angular field of view of the sensor (Fig. 5.4B). The segment of the ground surface measured within the IFOV is normally a circle of diameter D given by

D = è* H ………………...(1)

where,

D = diameter of the circular ground area viewed,

H = flying height above the terrain, and

è = IFOV of the system (expressed in radians).

The ground segment sensed at any instant is called ground resolution element or resolution cell.

As you go up in the sky/ space, your field of view (FOV), i.e. the total view angle of the sensor, increases. The FOV defines the swath. Swath is the width of the strip of the ground, i.e. recorded by the camera or sensor.

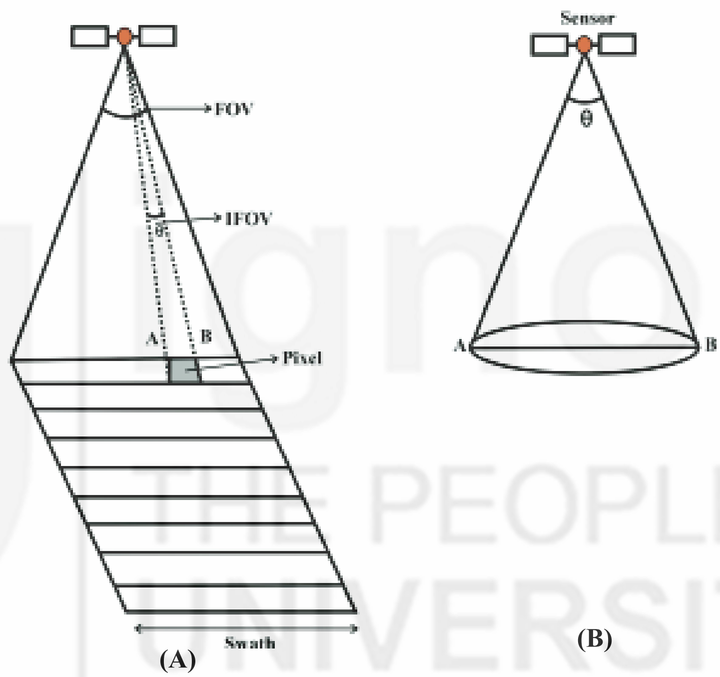
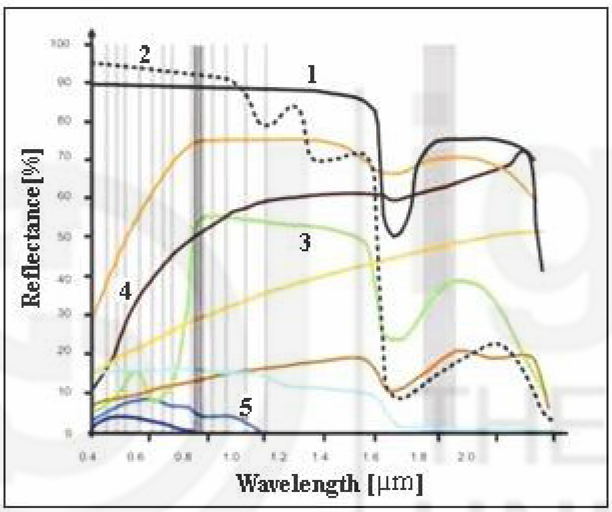


Fig. 5.4: Schematics showing (A) relationship of IFOV and FOV and (B) concept of IFOV

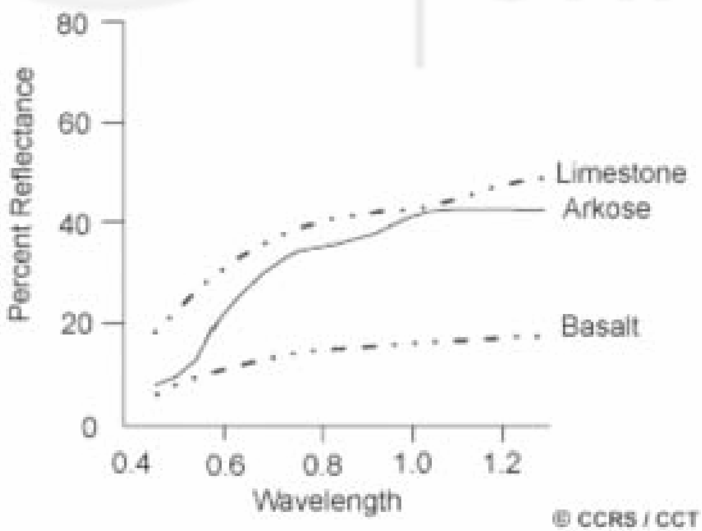
Spatial resolution of remote sensing system is influenced by the swath width. Spatial resolution and swath width determine the degree of detail that is revealed by the sensors and the area of coverage. Remote sensing sensors are generally categorised into coarse, intermediate and high spatial resolution sensors based on their spatial resolution. Sensors having coarse resolution provide much less detail than the high spatial resolution sensors. Because of the level of details the sensors provide, they are used for mapping at different scales. High spatial resolution sensors are used for large scale mapping (small area mapping) whereas coarse spatial resolution data are used for regional, national and global scale mapping.

5.3.2 Spectral Resolution

We all know that the Sun is a major source of electromagnetic radiation used in the optical remote sensing. Different materials on the Earth's surface exhibit different spectral reflectance and emissivities. The differences (variations) in reflectance and emissivities are used to distinguish features. However, the spectral signature does not give continuous spectral information and rather it gives spectral information at some selected wavelengths. These wavelength regions of observation are called gives spectral information at some selected wavelengths. These wavelength regions of observation are called *spectral bands*. The spectral bands are defined in terms of a ‘central wavelength’ and a ‘band width’. For example, a sensor which is making measurements at green wavelength region (0.5 µm-0.6 µm) will have central wavelength 0.55 µm and band width is 0.1 µm. Besides the location of the central wavelength and band width, total number of bands is also another important aspect of spectral band selection. The number and dimension of specific wavelength intervals in the electromagnetic spectrum to which a remote sensing instrument is sensitive is called *spectral* resolution. The use of well-chosen and sufficiently numerous spectral bands is a necessity. The selection of spectral band location primarily depends on the feature characteristics. The finer the spectral resolution, narrower the wavelengths range for a particular band (Fig. 5.5) and as you know the values of spectral reflectance of objects averaged over different, well-defined wavelength intervals comprise spectral signature of the object or feature by which they can be distinguished.



(a)



(b)

Fig. 5.5: Spectral reflectance signature of (a) different targets including (1) cloud, (2) snow, (3) vegetation, (4) soil and (5) water along with location of IRS-P3 MOS-A, B and C sensor channels and (b) various rock types (source: Navalgund et. al, 2007 and www.nrcan.gc.ca/earth-sciences/geography-boundary/remote-sensing/fundamentals/2234)

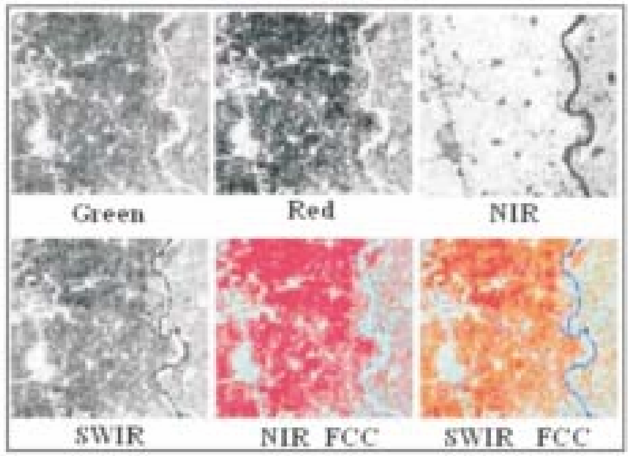


Fig. 5.6: Spectral variations of remote sensing data (source: Navalgund et. al, 2007). NIR – near infrared, SWIR – shortwave infrared, NIR FCC – near infrared false colour composite and SWIR FCC – shortwave infrared false colour composite

Spectral resolution describes ability of a sensor to define fine wavelength intervals. The finer the spectral resolution, the narrower the wavelength ranges for a particular channel or band. It can also be defined as the number and dimension of specific wavelength intervals in the electromagnetic spectrum to which a remote sensing instrument is sensitive. High spectral resolution means that sensor distinguishes between very narrow bands of wavelength. Spectral channels containing wide intervals in the electromagnetic spectrum are referred to as coarse spectral resolution and narrow intervals are referred to as fine spectral resolution. Black and white film records wavelength extending entire visible portion of the electromagnetic spectrum. Colour film has higher spectral resolution, as it is individually sensitive to the reflected energy at blue, green, and red wavelengths of the spectrum.

Refer to Unit 10 *Characteristics of Digital Remote Sensing Images* for details on quantisation, bits and bit depth.

Spectral response and emissivity curves characterise the reflectance and/or emittance of a feature or target over a variety of wavelengths. Different classes of features and details in an image can often be distinguished by comparing their responses over distinct wavelength ranges. Broad classes, such as water and vegetation, can usually be separated using very broad wavelength ranges (Fig. 5.6).

Other more specific classes, such as different rock types, may not be easily distinguishable using either of these broad wavelength ranges and would require comparison at much finer wavelength ranges to separate them (Fig. 5.5). Sensors are designed to record a specific portion of the electromagnetic spectrum. Sensors which record radiation over a wide part of visible spectrum in a single waveband are called *panchromatic*. Many remote sensing sensors record energy over several separate wavelength ranges at various spectral resolutions such sensors are referred to as *multi-spectral* sensors having few wide bands. Individual bands and their widths determine the degree to which individual targets (vegetation species, crop or rock types) can be determined on a multi-spectral image. Advanced multi-spectral sensors called *hyperspectral* sensors, detect dozens or hundreds of very narrow spectral bands throughout the visible, near-infrared, and mid-infrared portions of the electromagnetic spectrum. As you have been briefly introduced to the hyperspectral remote sensing in Unit 2 *Recent Trends in Geoinformatics*, Block 1 of MGY-001. Hyperspectral remote sensing deals with imaging at narrow spectral bands over a continuous spectral range and produce the spectra of all pixels in the scene. Hence, hyperspectral data is used to detect the subtle changes in vegetation, soil, water and mineral reflectance.

5.3.3 Radiometric Resolution

As the arrangement of pixels describes spatial structure of an image, the radiometric characteristics describe actual information content in an image. The information content in an image is determined by the number of digital levels (quantisation levels) used to express the data collected by the sensors. In other words, a definite number of discrete quantisation levels are used to record (digitise) the intensity of flow of radiation (radiant flux) reflected or emitted from ground features. The smallest change in intensity level that can be detected by a sensing system is called *radiometric* resolutions. The quantisation levels are expressed as *n* binary bits, such as 7 bit, 8 bit, 10 bit, etc. 8 bit digitisation implies 2^8 or 256 discrete levels (i.e. 0-255). Similarly, 7 bit digitisation implies 2^7 or 128^{th} discrete levels (i.e. 0-127).

The radiometric resolution of an imaging system determines its ability to discriminate very slight differences in energy. Coarse radiometric resolution would record a scene using only a few brightness levels (i.e. at very high contrast) whereas fine radiometric resolution would record the same scene using many brightness levels. A 7 bit data is considered having coarse radiometric resolution in comparison to a 8 bit or 10 bit data. The higher the radiometric resolution of a sensor the more sensitive it is in detecting small differences in reflected or emitted energy. In other words, the higher the radiometric resolution, the better subtle differences of intensity or reflectivity can be represented. In practice, the effective radiometric resolution is typically limited by the noise level, rather than by the number of bits of representation.

As seen in Fig. 5.7, 4-bit quantisation (16 levels) seems acceptable as digitisation using a small number of quantisation levels does not affect very much the visual quality of the image. Each photograph has a dynamic range that is determined by its physical properties. Radiometric resolution also refers to the dynamic range or number of possible data-file values in each band. Dynamic range is the difference between a photograph's lightest and darkest areas.

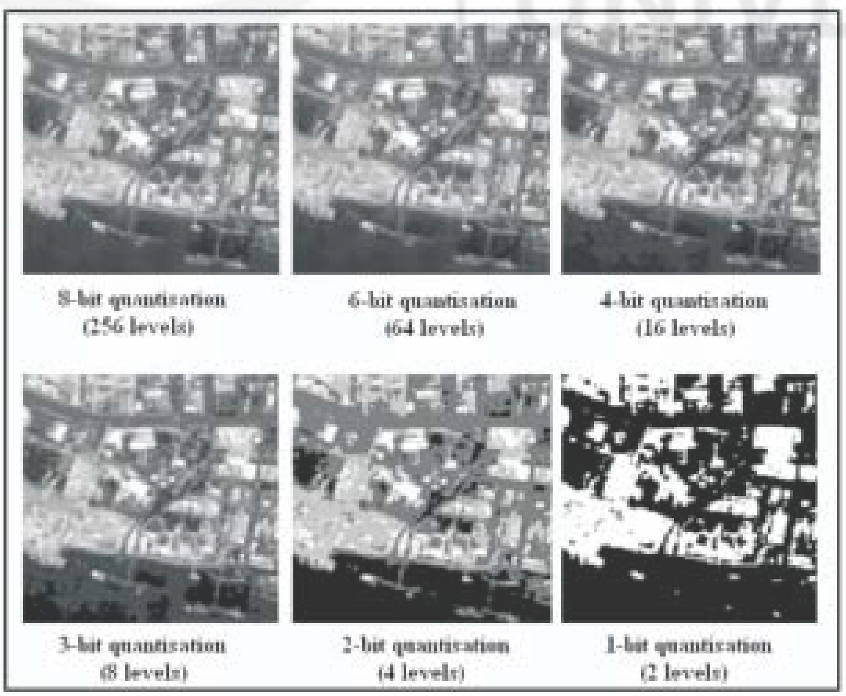


Fig. 5.7: Images showing the effect of degrading the radiometric resolution (source: www.crisp.nus.edu.sg/~research/tutorial/image.htm)

5.3.4 Temporal Resolution

In addition to spatial, spectral and radiometric resolution, it is also important to consider the concept of temporal resolution in a remote sensing system. As we have studied in Unit 1 *Principles of remote Sensing*, one of the advantages of remote sensing is its ability to observe a part of the Earth (scene) at regular intervals. The interval at which a given scene can be imaged is called *temporal* resolution. Temporal resolution is usually expressed in days. For instance, IRS-1A has 22 days temporal resolution, meaning it can acquire image of a particular area in 22 days interval, respectively. Low temporal resolution refers to infrequent repeat coverage whereas high temporal resolution refers to frequent repeat coverage. Temporal resolution is useful for agricultural application (Fig. 5.8) or natural disasters like flooding (Fig. 5.9) when you would like to re-visit the same location within every few days. The requirement of temporal resolution varies with different applications. For example, to monitor agricultural activity, image interval of 10 days would be required, but intervals of one year would be appropriate to monitor urban growth patterns.

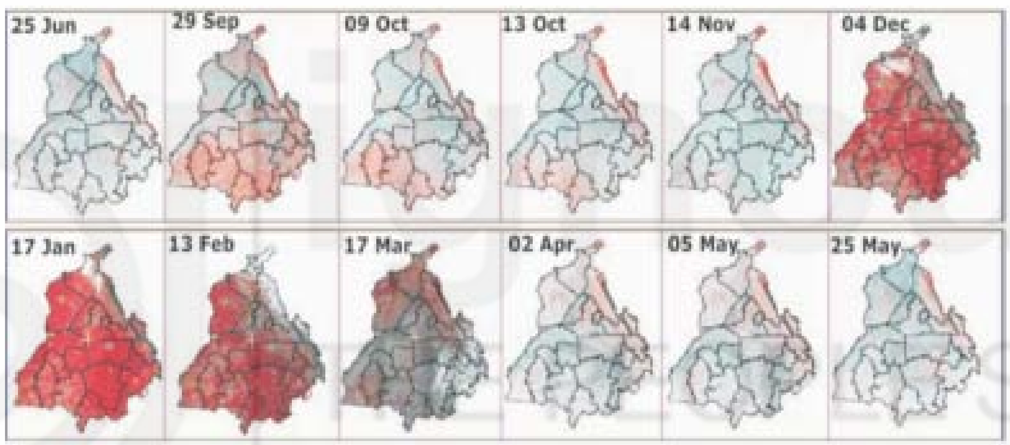


Fig. 5.8: Temporal variations of remote sensing data used to monitor changes in agriculture, showing crop conditions in different months (source: Navalgund et. al, 2007)

Fig. 5.9: Showing the importance of temporal resolution. View of the flood situation at Brisbane, Australia (a) pre flood and (b) post flood (source: http://abc.net.au)

approximately 0945 h and 1030 h local sun time, respectively. However, this is subject to slight variation due to orbital perturbations. Both satellites pass overhead earlier in the day north of the equator and later to the south. The cross track width of the imaging strip is an important parameter in deciding temporal resolution.

Check Your Progress I

1) Name the types of resolution in optical remote sensing.

.... ***Spend 5 mins***

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2) What is image resolution?

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3) Differentiate between coarse and fine radiometric resolution.

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5.4 RESOLUTION IN MICROWAVE REMOTE SENSING

The types of resolutions which you have studied in previous section pertain to the optical remote sensing. In microwave remote sensing, resolution is described in different terms. Now in this section we will be discussing about the resolutions in microwave remote sensing.

Microwave remote sensing employs microwave radiation using wavelengths that range from about 1 mm to 1 m, in particular, in the frequency interval from 40,000 to 300 MHz. This enables observations in all weather conditions without any restriction by cloud or rain. This is an advantage that is not possible with the optical remote sensing.

There are two types of microwave remote sensing: **Passive and Active.** In passive microwave remote sensing the wavelength are so long, the energy available is quite small compared to optical wavelengths. Thus, IFOV must be large to detect enough

There are two types of microwave remote sensing: **Passive and Active.** In passive microwave remote sensing the wavelength are so long, the energy available is quite small compared to optical wavelengths. Thus, IFOV must be large to detect enough energy to record a signal. Most passive microwave sensors are therefore characterised by low spatial resolution. Active remote sensors are generally divided into two distinct categories: imaging and non-imaging. The most common form of imaging active microwave sensors is imaging RADAR. RADAR is an acronym for *Radio Detection And Ranging*, which essentially characterises the function and operation of a radar sensors. Unlike optical systems, radar's spatial resolution depends on specific properties of the microwave radiation and its geometrical effects. Imaging radar is classified into *real aperture radar* (RAR) and *synthetic aperture radar* (SAR). Spatial resolution varies in these two cases. Radar resolution has two dimensions which are *range* (across-track) and *azimuth* (along-track) as shown in Fig. 5.10.

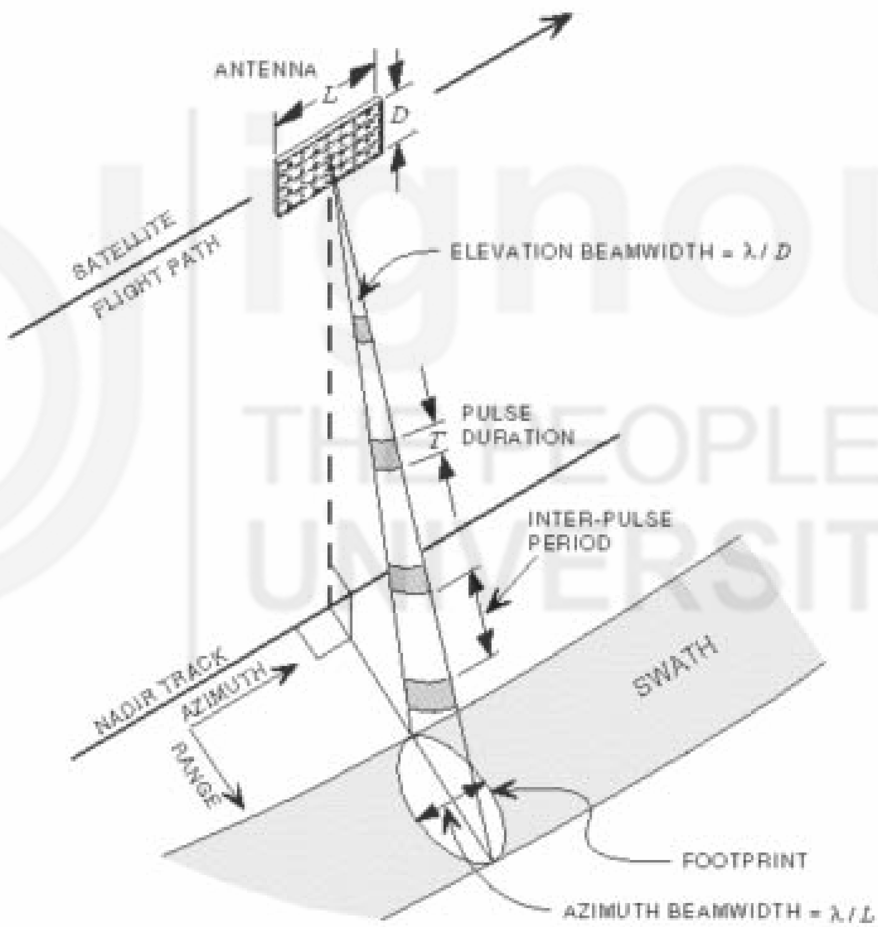

Fig. 5.10: Range (D) refers to the across-track dimension perpendicular to the flight direction, while azimuth (E) refers to the along-track dimension parallel to the flight direction. Similar to optical systems, the platform travels forward in the flight direction with the nadir directly beneath the platform. The microwave beam is transmitted obliquely at right angles to the direction of flight illuminating a swath which is offset from nadir (source: Gonzalez and Woods, 2002)

The ground resolution cell size of a SLAR (Side-Looking Airborne Radar) system is controlled by two independent sensing system parameters: pulse length and antenna beam width. A shot of electromagnetic energy that radar sends out in a straight line to detect a target is known as *pulse*. It is measured in terms of time (the interval between two such successive burst). The radar beam width is inversely proportional to the antenna length (also referred to as aperture), which implies that a longer antenna (or aperture) produces a narrower beam and finer resolution. Finer along-track resolution can be achieved by increasing the antenna length. Unlike optical systems, radar's spatial resolution depends on specific properties of the microwave radiation and its geometrical effects. If a RAR is used for imaging purpose (as in SLAR), a single transmit pulse and the back scattered signal are used to form the image. In this case, the resolution is dependent on the effective length of the pulse in the slant range direction and on the width of the illumination in the azimuth direction. Resolution is determined by antenna beam width in the along-track direction.

The *range* or *across-track* resolution is the ability of the radar to discriminate two targets that are closely spaced in range. For example, a range resolution of 10 m means that two targets that are on the same azimuth and 10 m apart in range can be resolved. It is dependent on the length of the pulse (P), as shown in Fig. 5.11 and Fig. 5.13. Two distinct targets on the surface are resolved in the range dimension if their separation is greater than half the pulse length. For example, in Fig. 5.11, targets 1 and 2 are not separable while targets 3 and 4 can be easily separated into ground range coordinates; the resolution in ground range is dependent of the incidence angle. Thus, for fixed slant range resolution, the ground range resolution decreases with increasing range.

$$R_r = \frac{Tc}{2 \cos \gamma} \quad \text{...} \quad (2)$$

Where,

T = duration of the radar pulse,

c = speed of light, and

γ= depression angle

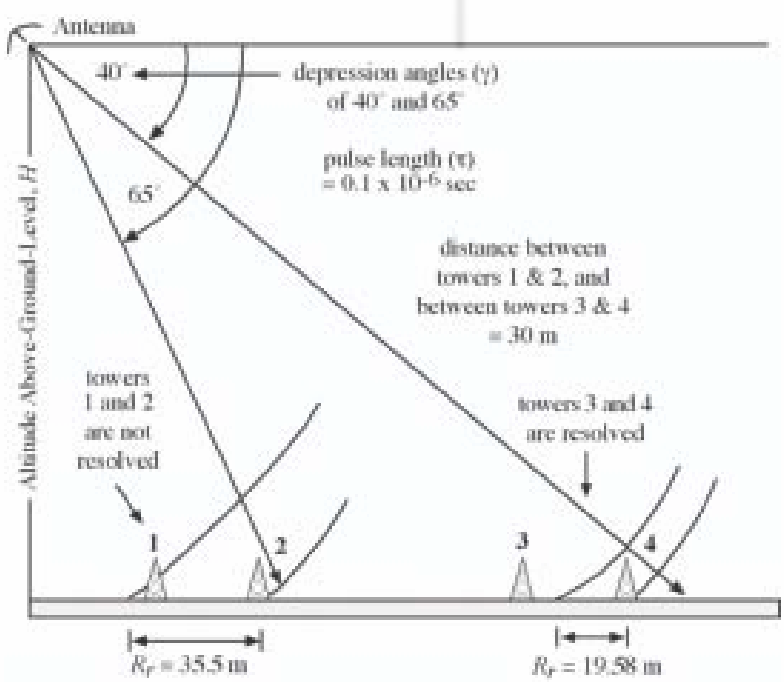

Fig. 5.11: Range or across-track spatial resolution (source: Gonzalez and Woods, 2002)

The *azimuth or along-track* resolution is determined by the angular width of the radiated microwave beam and the slant range distance. Thus, beam width is a measure of the width of the illumination pattern (Figs. 5.12 and 5.13). As the radar illumination propagates to increasing distance from the sensor, the azimuth resolution decreases (becomes coarser). The radar beam width is inversely proportional to the antenna length (also referred to as the aperture), which implies that a longer antenna (or aperture) produces a narrower beam and finer resolution. Finer along-track resolution can be achieved by increasing the antenna length. In Fig. 5.12, targets 1 and 2 in the near range are separable, but targets 3 and 4 at further range are not, though the distance between 1 and 2 is equal to the distance between 3 and 4.

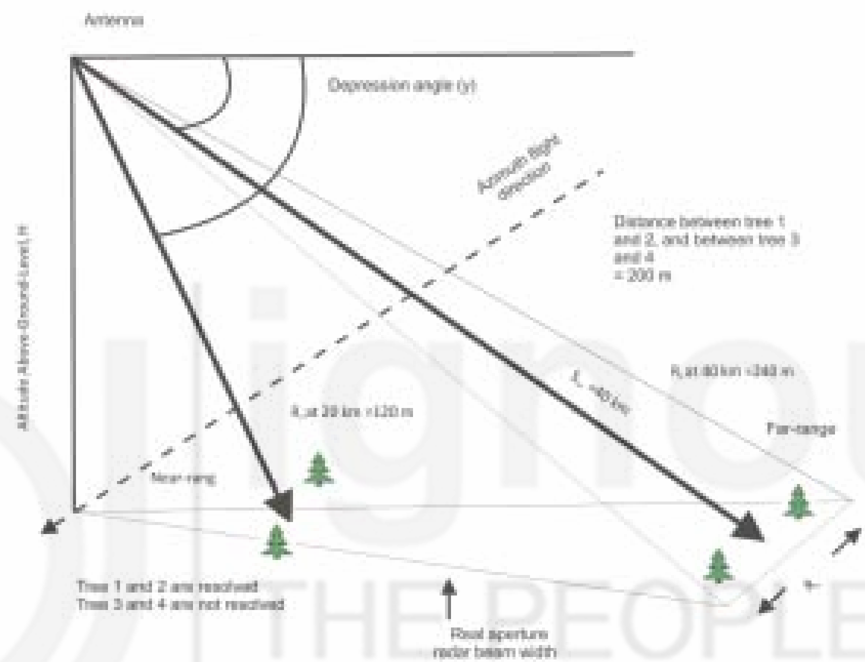

Fig. 5.12: Azimuth resolution or along track spatial resolution (source: Gonzalez and Woods, 2002)

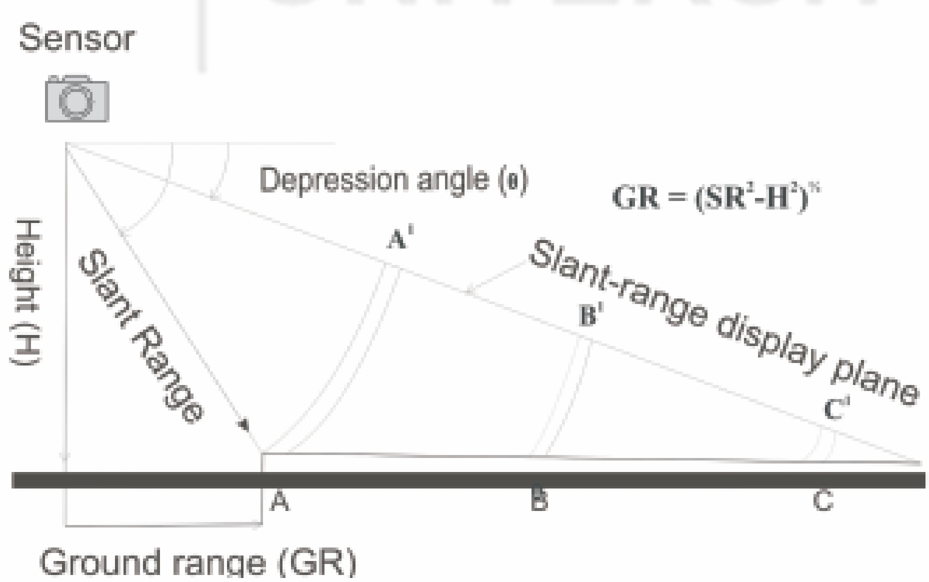

Fig. 5.13: Relationship between slant range resolution and ground range resolution (source: Gonzalez and Woods, 2002)

5.5 RELATIONSHIP BETWEEN DIFFERENT TYPES OF RESOLUTION

You have read in earlier sections that the arrangement of pixels describes spatial structure of an image whereas radiometric characteristics describe the actual information content in an image. The radiometric resolution of an imaging system describes its ability to discriminate very slight differences in energy. The finer the radiometric resolution of a sensor; the more sensitive it is to detecting small differences in reflected or emitted energy. In addition to above basic parameters, sensor must also have a high geometric fidelity, and images of different bands should be well registered to enable multi-spectral classification.

Most first-time users of remote sensing assume that higher resolution provides more detail which, in turn, must yield more information for feature identification and analyses. Although it is true that higher resolution generates more data, however, it is not always synonymous with more information.

The particular challenge in monitoring land areas is to capture the patterns of spatially detailed land cover change, within the context of seasonal land cover dynamics (Fig. 5.14). Imagery is always acquired within a spatial, spectral and temporal context. Fig. 5.14 depicts the relation between spatial resolution and temporal resolution in various types of data.

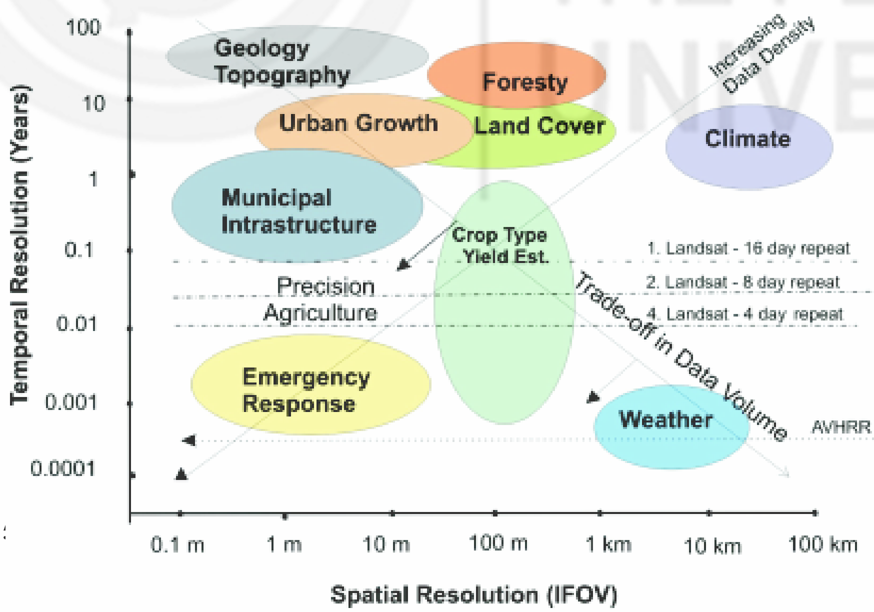

Fig. ... ne ...)1;

Images acquired repetitatively through time record the dynamics of surface cover change that result from biophysical, geochemical, and socio-economic processes operating within the Earth system. Remote sensing provides the facility of monitoring the sudden and short lived changes, requiring swift data acquisition and analyses to monitor and evaluate the impact of events such as storms, tsunamis, hurricanes, flood, effluent discharge, droughts, forest fire, locust plagues, dispersion rate of oil slicks and development and movement of phytoplankton blooms in estuaries. In some instances, more detail merely introduces noise that obscures identification of features of interest, for example, we do not need to discern every grassy patch in order to determine whether the area is urban or farmland.

There are trade-offs between spatial, spectral, and radiometric resolution which are taken into consideration when engineers design a sensor. For high spatial resolution, the sensor has to have a small IFOV. However, this reduces the amount of energy that can be detected as the area of the ground resolution cell within the IFOV becomes smaller. This leads to reduced radiometric resolution i.e. the ability to detect fine energy differences. To increase the amount of energy detected (and radiometric resolution) without reducing spatial resolution, we have to broaden the wavelength range detected for a particular channel or band. Unfortunately, this reduces the spectral resolution of the sensor. Conversely, coarser spatial resolution would allow improved radiometric and/or spectral resolution. Thus, these three types of resolution must be balanced against the desired capabilities and objectives of the sensor.

You have seen that the timely use of remote sensing information, which has increased over past twenty years, provides information essential for monitoring and mitigating environmental problems that occur suddenly on a big scale. The ability to obtain data rapidly and inexpensively over large geographic regions means that remote sensing can help us document the local, regional and global consequences of acute and chronic changes in ecosystems and environment. Finally, in addition to its spatial and temporal advantages remote sensing offers the advantage of a wide spectral coverage. During the geological fieldwork our eyes are capable of detecting particular lithology based on the colour and we have no difficulty in distinguishing sandstone from granite based on colour. Because different lithology reflects radiation and their colour or spectral signature often contrasts with that of the background, we can use remote sensing to identify and detect rock-types within the landscape.

Check Your Progress II

Spend 5 mins

1) Name the types of resolution in microwave remote sensing.

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2) Differentiate between azimuth and range resolution.

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5.6 ACTIVITY

Take a photograph of an object in the maximum resolution (megapixel) of your digital camera. Take two or more photographs of the same object using the same camera but in reduced resolution (megapixel). Look at the quality and note down the details of each photograph at different resolutions.

5.7 SUMMARY

Let us summarise, what you have studied in this unit:

- Resolution of a sensor system may be defined as its capability to discriminate two closely spaced objects from each other.
- Image resolution can be measured in various ways like spatial, spectral, temporal and radiometric resolutions.
- Spatial resolution can broadly be described as the ground surface area that forms one pixel in the satellite image.
- Spectral resolution describes ability of a sensor to define fine wavelength intervals.
- Radiometric resolution of an imaging system describes its ability to discriminate very slight differences in energy.
- Temporal resolution is the shortest amount of time between image acquisitions of a given location.
- The resolution of radar is its ability to distinguish between targets that are very close in either range or bearing.
- Range resolution is the ability of a radar system to distinguish between two or more targets on the same bearing but at different ranges, while azimuth resolution refers to the along-track dimension parallel to the flight direction.

5.8 UNIT END QUESTIONS

Spend 30 mins

1) Explain in brief the different types of image resolution.
2) Mention the factors affecting image resolution.
3) What is the difference between spatial and temporal resolution?
4) What do you understand by resolution in microwave remote sensing?

5.9 REFERENCES

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- www.crisp.nus.edu.sg/~research/tutorial/image.htm
- www.nrcan.gc.ca/earth-sciences/geography-boundary/remote-sensing/fundamentals/2234

All the above websites were retrieved on 25th February 2011.

5.10 FURTHER/SUGGESTED READINGS

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- Drury, S.A. (1990) *A Guide to Remote Sensing*, Oxford, 199p.
- Sabins, F.F. (1987) *Remote Sensing Principles and Interpretation*, 2nd Ed., W.H. Freeman & Co., 449p.

5.11 ANSWERS

Check Your Progress I

1) Spatial, spectral, radiometric and temporal
2) Refer beginning of the sections 5.1 and 5.2.
3) Refer section 5.3.3.

Check Your Progress II

1) Range or across-track resolution and azimuth or along-track resolution.
2) Refer section 5.4

Unit End Questions

For question, 1 and 2 refer section 5.1 and 5.2, respectively.

For question, 3 and 4 refer section 5.3 and 5.4, respectively.

UNIT 6 MAJOR SPACE PROGRAMMES

Structure

6.1 INTRODUCTION

You have studied in Units 4 and 5 that each remote sensing satellite is equipped with a certain type of sensors. From 1957, when the Sputnik satellite was launched by Russia, to the present a number of satellites have been launched by many countries. These satellites, launched under different space programmes, carried with them sensors of different characteristics to gather relevant data about the Earth. The data obtained by satellites have become increasingly important for predicting weather, studying hazards, monitoring global change and managing Earth resources. In this unit, you will be introduced to important space programmes of India and other countries and also the characteristics of the sensors and their utilities.

Objectives

After studying this unit, you should be able to:

- outline the initiatives taken by various countries for space exploration;
- discuss the achievements of Indian space programme; and
- explain the importance of various types of satellites launched by different countries.

6.2 SPACE PROGRAMMES

A space programme commonly includes space missions and their planning. A space mission is the journey of the space by a manned or unmanned vehicle (spacecraft/satellite), aiming to explore solar system and gather scientific data. A space mission programme includes planning, designing and operation of a specific space mission. The planning of a space mission is a complex and multi-disciplinary task which includes various aspects of the mission from its definition to the end of mission's life. According to objectives of the space mission, they can be categorised into the following:

- applications
- technology experiment, and
- science and exploration

The first step into space was taken after World War II, when Russia (USSR) successfully launched first artificial satellite, Sputnik-1, into the space in October, 1957. This marked the beginning of remote sensing era as it provided first view of Earth's surface from the space. Subsequently, in the same year United States of America took leap into space age by launching its first satellite, Explorer-1. On 1st October, 1958, United States of America established National Aeronautics and Space Administration (NASA) for space exploration. But the space age really began with the launch of Vostok-1 on 12th April 1961 by Russia. The space shuttle took Yuri Gagarin (a Russian cosmonaut) into space. Apart from USSR and USA, many other countries of the world including India have taken leap into the space exploration as shown in Table 6.1.

Table 6.1: Space agencies of the world

S.No	Country	Agency	Website
1.	Australia	Australian Space Research Institute (ASRI)	www.asri.org.au
2.	Belgium	Belgian Institute for Space Aeronomy (BISA)	www.aeronomie.be
3.	Brazil	Brazilian Space Agency (AEB)	www.cbers.inpe.br
4.	Canada	Canadian Space Agency (CSA)	www.asc-csa.gc.ca
5.	China	China National Space Administration (CNSA)	www.cnsa.gov.cn
6.	Europe	European Space Agency (ESA)	www.esa.int
7.	France	French Space Agency (CNES)	www.cnes.fr
8.	Germany	German Aerospace Center (DLR)	www.dlr.de
9.	India	Indian Space Research Organisation (ISRO)	www.isro.org
10.	Iran	Iranian Space Agency (ISA)	www.isa.ir
11.	Italy	Italian Space Agency (ASI)	www.asi.it
12.	Japan	Japan Aerospace Exploration Agency (JAXA)	www.jaxa.jp
13.	Netherlands	Netherlands Institute for Space Research (SRON)	www.sron.nl
14.	Russia	Russian Federal Space Agency (RKA)	www.federalspace.ru
15.	South Korea	Korea Aerospace Research Institute (KARI)	www.kari.kr
16.	Spain	Instituto Nacional de Tecnica Aeroespacial (INTA)	www.inta.es
17.	Sweden	Swedish National Space Board (SNSB)	www.snsb.se
18.	Ukraine	National Space Agency of Ukraine (NSAU)	www.nkau.gov.ua
19.	United States	National Aeronautics and Space Administration (NASA)	www.nasa.gov
20.	United Kingdom	UK Space Agency (UKSA)	www.bis.gov.uk

6.3 INDIAN SPACE PROGRAMME

Indian space programme started way back in 1920s, when a scientist, S.K. Mitra conducted a series of experiments to sound the atmosphere using ground based radio techniques in Kolkata. From 1950, Government of India (GOI) started to invest in space science programmes. From 1950 to 1962, Department of Atomic Energy provided funds for research in space sciences. For the development and formulation of Indian space programmes, GOI established the Indian National Committee for Space Research (INCOSPAR) in 1962 under the leadership of visionary Dr. Vikram Sarabhai. Dr. Vikram Sarabhai is considered as father of Indian space programme (Fig. 6.1). In 1963, INCOSPAR took decision to setup Thumba Equatorial Rocket Launching Station (TERLS) at Thumba, Thiruvananthapuram, South India. The setting up of TERLS marked beginning of the Indian space age. Later on, in June 1972, GOI established the Space Commission and Department of Space (DOS) for promoting unified development and application of space science and technology at national level. In the meantime, during 1969, Dr. Vikram Sarabhai re-designated INCOSPAR as the Indian Space Research Organisation (ISRO), Bangalore and it was brought under DOS in September, 1972. ISRO set up as a research and development wing of DOS which is responsible for the execution of India's national space programme.

Fig. 6.1: Dr. Vikram Sarabhai – father of Indian space programme

The space programme of India was pioneered with a vision to use space technology for national development. The programme is application driven with due emphasis on policy of self-reliance. The primary objective of the Indian space programme is to establish operational space services in a self-reliant manner in thrust areas of satellite communication, satellite based resource survey/management and meteorological applications. The indigenous development of satellites, launch vehicles and associated ground segment for providing these services is integral part of these programmes.

Indian Space Research Organisation (ISRO) is the nodal body for space research under the control of GOI. It is one of the leading space research organisations in the world. It was constituted in its modern form in 1969 with an objective to develop space technology and its application to various tasks of the nation. Indian space programmes are executed through ISRO with four grant-in-aid institutions namely - National Remote Sensing Centre (NRSC), Hyderabad; Physical Research Laboratory (PRL), Ahmedabad; National Atmospheric Research Laboratory (NARL), Tirupati and North-Eastern Space Applications Centre (NE-SAC), Umiam, Meghalaya.

Indian space programme has made impressive stride with its inception in the late 1950s. But during the initial stages, India relied heavily on international assistance and co-operation to develop its space programme. Later India entered in the space age with launching of the first Indian scientific low orbit satellite *Aryabhatta* in April 1975 with the help of *Cosmos-3M* launch vehicle of Soviet Union. Aryabhatta was followed by launching of two Indian satellites for remote sensing namely *Bhaskara-1* in 1979 and *Bhaskara-2* in 1981. India's first three-axes stabilised geostationary tele-communications satellite *APPLE* (Ariane Passenger Payload Experiment) was successfully launched in June 1981 by the European *Ariane* launch vehicle. The other major breakthrough in the Indian space programme includes launch of *SITE*

(Satellite Instructional Television Experiment) which was an experimental satellite communications project of India launched jointly by NASA and ISRO in 1975. The project made available Special Instructional and Educational Television Programme directly to rural India. *STEP* (Satellite Telecommunications Experiments Project) was carried out using the Franco-German satellite Symphonie in 1977 for telecommunication experiments.

ISRO's Rohini satellite (RS-1) was launched with its own launch vehicle in 1979. This made India the seventh nation in the globe to achieve the capability to launch a satellite. Indian satellite launch vehicle (SLV-3) was used to launch Rohini Satellites (RS-1) and (RS-D1) in 1979 and 1981, respectively.

Let us now discuss about the two major series of satellite systems established by ISRO.

- **Indian Remote Sensing Satellite (IRS) Series -** this series has been developed for resources monitoring and management.
- **Indian National Satellite (INSAT) Series -** this series provide services for tele-communications, TV broadcasting and meteorology services including disaster warning support.

IRS series of satellites are in the polar orbit whereas satellites of INSAT series are in geostationary orbit. ISRO has developed two satellite launch vehicles, Polar Satellite Launch Vehicle (PSLV) and Geostationary Satellite Launch Vehicle (GSLV) to place IRS and INSAT satellites in the required orbits, respectively. Apart from IRS and INSAT series, ISRO also launched CARTOSATs and radar imaging satellites (RISATs).

6.3.1 Indian Remote Sensing Satellite Series

It is important to note that besides IRS and INSAT series of satellites, India has also made stride toward space exploration by launching Chandrayaan-1 in 2008.

After successful launching of Bhaskara-1 and 2 satellites in space during 1979 and 1981, respectively, ISRO has started developing indigenous Indian remote sensing satellites series. This is named as *Indian Remote Sensing Satellites* (IRS) series. It is a series of Earth observation satellites that have been built, launched and maintained by ISRO. IRS system has the largest constellation of operational remote sensing satellites, which are providing continuity of services both at national and international level from 1988 onwards. IRS system collects data from the Earth's surface in several spectral bands but visible and near infrared are common with a variety of spatial resolutions starting from 360 m to 2.5 m. Data received from IRS series is disseminated to several countries across the globe.

The primary components of IRS mission are:

- to develop a three-axes stabilised polar sun-synchronous satellite with multispectral (pushbroom cameras) sensors for acquiring imagery for Earth resource applications,
- to establish ground based system for reception, recording and processing of multispectral data, and
- to use IRS data along with information obtained from other sources for surveying and managing of resources.

India has successfully launched 18 remote sensing satellites under IRS mission since

India has successfully launched 18 remote sensing satellites under IRS mission since 1988 (Table 6.2). The first Indian remote sensing satellite, IRS-1A was launched into near circular orbit in 1988 (Fig. 6.2) followed by the launching of second identical satellite, IRS-1B, in 1991. Both of them were placed at an altitude of 904 km in a sun-synchronous near polar orbit at an inclination of 99° and were launched from the Soviet Cosmodrome, Baikonure. IRS-1A and IRS-2B had two types of cameras known as *Linear Self Scanning Sensors* (LISS-I and LISS-II) operated in the pushbroom scanning mode using linear charged coupled devices (CCDs) arrays. Both had a repeat cycle (temporal resolution) of 22 days. IRS-1A collected data with a 72 m spatial resolution with a ground swath of 148 km, while IRS-1B system had a 36 m spatial resolution and 74 km ground swath. Both sensors acquired multispectral imagery in blue, green, red, and near infrared spectral regions.

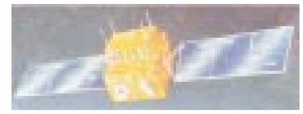

Fig. 6.2: IRS-1A satellite (source: www.isro.org)

Table 6.2: List of remote sensing satellites launched by India (after overview of Indian space sector, 2010)

S.No	Name of satellite	Date of launch	Launch vehicle	Mission status
1	IRS-1A	17th March, 1988	Vostok, USSR	Completed
2.	IRS-1B	29th August, 1991	Vostok, USSR	Completed
3.	IRS-P1	20th September, 1993	PSLV-D1	Crashed, due to launch failure of PSLV
4.	IRS-P2	15th October, 1994	PSLV-D2	Completed
5.	IRS-1C	28th December, 1995	Molniya, Russia	Completed
6.	IRS-P3	21st March, 1996	PSLV-D3	Completed
7.	IRS-1D	29th September, 1997	PSLV-C1	Completed
8.	IRS-P4 (Oceansat-1)	27th May, 1999	PSLV-C2	Completed
9.	Technology Experiment Satellite (TES)	22nd October, 2001	PSLV-C3	In service
10.	IRS-P6 (Resourcesat-1)	17th October, 2003	PSLV-C5	In service
11.	Cartosat-1 (IRS-P5)	5th May, 2005	PSLV-C6	In service
12.	Cartosat-2 (IRS-P7)	10th January, 2007	PSLV-C7	In service
13.	Cartosat-2A	28th April, 2008	PSLV-C9	In service
14.	IMS-1	28th April, 2008	PSLV-C9	In service
15.	RISAT-2	20th April, 2009	PSLV-CA	Completed
16.	Oceansat-2	23rd September, 2009	PSLV-C14	In service
17.	Cartosat-2B	12th July, 2010	PSLV-C15	In service
18.	Resourcesat-2	20th April, 2011	PSLV-C16	In service

The launch of IRS-P1 in 1993 was not successful because of the failure of indigenously developed Polar Satellite Launch Vehicle (PSLV-D1) in the last stage of launching operation; as a result, satellite and rocket plunged into sea. Subsequently, in October 1994, another satellite IRS-P2 was successfully launched by indigenously built PSLV-D2. It was placed in a polar sun-synchronous orbit at an altitude of about 817 km. IRS-P2 had only LISS-II camera, whose specifications were much similar to that of satellite IRS -1A/1B with small modifications in the arrangements of CCDs. IRS-P2 had revisit cycle of 24 days, combined ground swath 131 km with spatial resolution of 32 m across track and 37 m along track. Specifications of IRS sensor system are given in Table 6.3.

Table 6.3: Sensor specifications of IRS

Sensor type	Band	Specifications Spectral resolution (μm)	Spatial resolution (m)
LISS-I	1	0.45-0.52 (blue)	73
	2	0.52-0.59 (green)	73
	3	0.62-0.68 (red)	73
	4	0.77-0.86 NIR (Near-infrared)	73
LISS-II	1	0.45-0.52 (blue)	36
	2	0.52-0.59 (green)	36
	3	0.62-0.68 (red)	36
	4	0.77-0.86 NIR (Near-infrared)	36
LISS-III	1	0.52 - 0.59 (green)	24
	2	0.62 - 0.68 (red)	24
	3	0.77-0.86 NIR (Near-infrared)	24
	4	1.55-1.70 (mid-IR)	24
LISS-IV	1	0.52 - 0.59 (green)	6
	2	0.62 - 0.68 (red)	6
	3	0.77 - 0.86 NIR (Near-infrared)	6
	4	1.55 - 1.70 (mid-IR)	6
	pan	0.62-0.68 (red)	6
WiFS	1	0.62-0.68 (red)	188
	2	0.77-0.86 NIR (Near-infrared)	188
AWiFS	1	0.0.52-0.59 (green)	60
	2	0.62-0.68 (red)	60
	3	0.77-0.86 NIR (Near-infrared)	60
	4	1.55-1.70 (mid-IR)	60

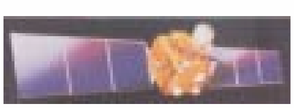

Fig. 6.3: IRS-1C satellite (source: www.isro.org)

The second generation remote sensing satellites IRS-1C (Fig. 6.3) and IRS-1D were successfully launched into polar orbit in December, 1995 and September, 1997, respectively. IRS-1C was launched by a Russian launch vehicle, Molniya and IRS-1D by an indigenous built PSLV-C1. Both satellites are featured by improved spatial resolution, extended spectral bands, stereo viewing, wide swath and fast revisit capability. The satellites contain three sensors namely - Panchromatic Camera (PAN), LISS-III and Wide Field Sensor (WiFS) for collecting panchromatic and multispectral image data at varying resolutions. IRS-1C/1D missions have been continuation of IRS-1A/1B with improved spatial resolution. IRS-1C and 1D have slightly different orbits as a result they do not have the same reference system. IRS-1C operates in a circular, sun-synchronous, near polar orbit with an inclination of 98.69° at an altitude of 817 km. This satellite takes 101.35 minutes to complete one revolution around the Earth and completes about 14 orbits per day. The entire Earth is covered by 341 orbits during a 24 day cycle. IRS-1D launched in September, 1997, entered in a wrong elliptical orbit due to problem associated with launching vehicle (PSLV-C1). But satellite and quality of data produced by it appears to be good.

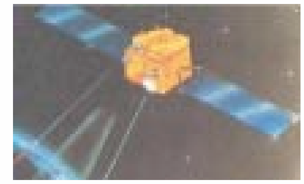

Fig. 6.4: IRS-P3 satellite (source: www.isro.org)

Satellite IRS-P3 was launched successfully in March 1996 from Sriharikota, South India by third indigenously built PSLV-D3 launch vehicle (Fig. 6.4). IRS-P3 was a follow-up project of IRS-P2. In addition to WiFS similar to the IRS-1D, with an additional Short Wave Infrared Band (SWIR); IRS-P3 also had a Modular Opto-electronic Scanner (MOS) and an X-ray astronomy payload. MOS was dedicated for remote sensing of ocean colour and the study of atmosphere. This mission completed in January 2006.

Oceansat

IRS-P4 (Oceansat-1) satellite was launched in May, 1999 from Sriharikota by PSLV-C2 flight. It is placed at an altitude of 720 km with an inclination of 98.28° in a polar sun-synchronous orbit. The satellite has two sensor payloads namely an Ocean Colour Monitor (OCM) and Multi-frequency Scanning Microwave Radiometer (MSMR). Since it represents the first satellite primarily devoted to oceanographic applications, it is commonly known worldwide as *Oceansat-1*. Technical characteristics of OCM are given in Table 6.4.

Table 6.4: Specifications and features of OCM

Parameters	Specifications
IGFOV at nominal altitude (m)	360 x 250
Swath (km)	1420
Spectral bands	8
Spectral bands (nm)	B1: 404-424 B2: 431-451 B3: 476-496 B4: 500-520 B5: 546-566 B6: 610-630 B7: 725-755 B8: 845-885
Quantisation bits	12
Along track steering	± 20°
Data acquisition modes	Local and global area coverage

For providing continuity of operational services of Oceansat-1, ISRO launched Oceansat-2 along with six nano European satellites in September, 2009 by PSLV-C14. The satellite has three payloads such as an OCM, a Ku-band pencil Beam Scatterometer (SCAT) and a Radio Occultation Sounder satellite dedicated to ocean research. It is placed at an altitude of 720 km with an inclination of 98.28°. The main objectives of Oceansat-2 include study of surface winds and ocean surface strata, observation of chlorophyll concentrations, identification of potential fishing zones, monitoring of phytoplankton blooms, study of atmospheric aerosols, suspended sediments in the water and providing inputs for general meteorological observations.

Resourcesat

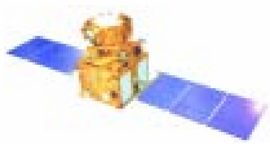

Fig. 6.5: Resourcesat-1 satellite (source: www.isro.org)

Resourcesat-1 (Fig. 6.5) is the most advanced remote sensing satellite built by ISRO and was launched in October, 2003 by PSLV-C5. It is the tenth satellite of the IRS series and is also known as IRS-P6. It is placed at an altitude of 817 km in a sun-synchronous polar orbit. Resourcesat-1 is designed to provide continuity of the remote sensing data services of IRS-1C/1D in both multispectral and panchromatic imagery. It contains three sensor system viz. LISS-III, LISS-IV, and Advanced Wide Field Sensor (AWiFS) with greatly improved spatial resolutions. Data products obtained from this satellite may be used for advanced applications in vegetation dynamics, disaster management, crop yield estimates, etc. In 2011, ISRO has launched Resourcesat-2, which is a follow on mission to Resourcesat-1. Resourcesat-2 is an improved version of Resourcesat-1. It is placed at an altitude of 822 km in a circular polar sun-synchronous orbit.

National Remote Sensing Centre (NRSC), Hyderabad (A.P.), is continually acquiring and archiving data from IRS series. In addition, data from other contemporary satellites are also being received. Data collected by IRS series can be used for pre-harvest crop acreage and production estimates, monitoring of seasonal drought, flood damage assessment, landuse and landcover mapping, planning of agro-climatic zones, monitoring of forest covers, soil mapping, determination of potential fishing zones and sustainable development of the country.

Cartosat

Since 2005, ISRO has launched four CARTOSATs namely - CARTOSAT-1, CARTOSAT-2, CARTOSAT-2A and CARTOSAT-2B (Fig. 6.6). CARTOSAT-1(also known as IRS-P5) is a stereoscopic Earth observation satellite operating in a sun-synchronous orbit that is primarily deployed for cartographic applications. It was launched in May, 2005 by PSLV-C6 from the newly built second launch pad at Sriharikota. It contains two panchromatic cameras that capture black and white stereoscopic pictures. The imageries have a spatial resolution of 2.5 m and cover a swath of 30 km. CARTOSAT- 2 (also known as IRS-P7) is another Earth observation satellite having a circular polar sun-synchronous orbit and capable of providing scene-specific imageries for cartographic applications. It was launched by PSLV in January, 2007 and was placed at an altitude of 630 km above the Earth with an inclination of 97.91°. Its panchromatic camera provides less than 1m spatial resolution imageries with a ground swath of 10 km.

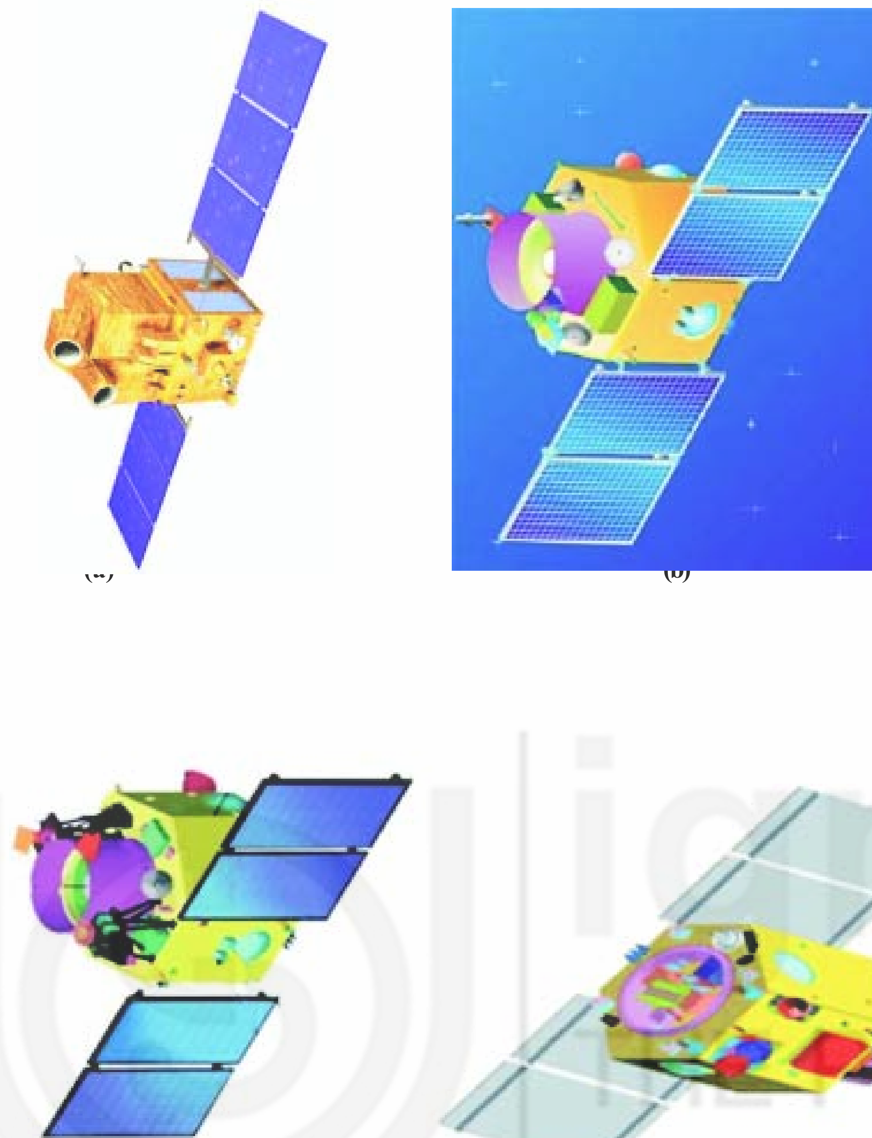

Fig. 6.6: Schematics of (a) CARTOSAT-1, (b) CARTOSAT-2, (c) CARTOSAT-2A and (d) CARTOSAT-2B satellites (source: www.isro.org)

CARTOSAT-2A was launched by PSLV-C9 in April, 2008 along with an Indian mini satellite (IMS-1) and eight other nano research satellites belonging to Canada, Denmark, Germany, Japan and Netherlands. It was placed at an altitude of 635 km with an inclination of 97.94°. It contains a panchromatic camera having a spatial resolution better than 1m and swath of 9.6 km. Data products of the satellites can be used for cartographic applications like mapping, urban and rural infrastructure development and management as well as application in land information and GIS. CARTOSAT-2B is the latest and an advanced Indian remote sensing satellite. It represents seventeenth satellite in the IRS series and was launched in July, 2010 by PSLV-C15 along with Algerian satellite, one nano satellite each from Canada and Switzerland and StudSat, a pico satellite from Sriharikota. It was placed at an altitude of 630 km in a polar sun-synchronous orbit at an inclination of 97.71°.

CARTOSAT-2B carries a panchromatic camera similar to CARTOSAT-2 and 2A. It is capable of imaging a swath of 9.6 km with a resolution of 0.8 m. The scene specific spot panchromatic imagery of CARTOSAT-2B is useful for cartographic and a host of other applications. The satellite has high agility with capability to steer along as well as across the track up to ± 26° to obtain stereoscopic imagery and achieve a four to five day revisit capability.

6.3.2 Radar Imaging Satellite Series

Radar Imaging Satellites (RISAT) are a series of Indian radar (microwave) imaging reconnaissance satellites developed by ISRO. It differs from IRS series by having a multi-mode Synthetic Aperture Radar (SAR) as the sole payload for RISAT. Basically, SAR is an all weather imaging active sensor which is capable of taking images of the Earth in cloudy and snow covered regions and also both during day and night. RISAT provides advantages over the earlier Indian Earth observation satellites of IRS series which rely mainly on optical and spectral sensors which cannot image areas during night as well as covered by snow and clouds. RISAT-2 (Fig. 6.7) is the first satellite of the RISAT series. It was launched successfully by ISRO on 20th April, 2009 by PSLV-C12 along with micro ANUSAT from the Satish Dhawan Space Center, Sriharikota. It has C-band SAR payload operating in a multi-polarisation and multi-resolution mode. It is placed at an altitude of 550 km above the Earth's surface and having an inclination of 41°. RISAT-2 weighed about 300 Kg and was jointly manufactured by ISRO and Israel aerospace industries space division. On the other hand, ANUSAT which is the first experimental communication satellite developed by Anna University, Chennai under the overall guidance of ISRO demonstrates technologies related to message store and forward operations.

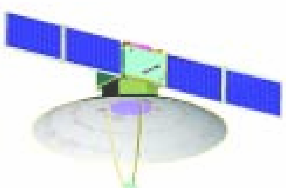

Fig. 6.7: RISAT-2 satellite (source: www.isro.org)

RISAT-2 enhances ISRO's capability in Earth observation with microwave remote sensing. Its basic focus is on agriculture and to provide requisite temporal sampling capability which is important for monitoring *Khariff* crop produced during monsoon season. The C-band frequency operation of RISAT-2 also ensures wide applicability data in the thrust areas like vegetation, forestry, soil moisture, geology, sea ice, coastal processes, man-made object identification, cyclones, landslides and flood mapping in a more effective way. RISAT-2 is also known as *spy satellite* as it helps security agencies of India to keep an eye on the country's borders round the clock.

6.3.3 Indian National Satellite Series

Indian National Satellites (INSAT) series is a series of geostationary communication satellites. It was commissioned with the launch of INSAT-1B in August 1983, shortly after the launch of satellites APPLE and INSAT-1A. It is a series of multi-purpose satellites launched by ISRO to provide indigenous services in telecommunications, broadcasting, meteorology, and search and rescue operations in India. It is developed jointly by the Department of Space (DOS), Department of Telecommunications (DOT), India Meteorological Department (IMD), All India Radio (AIR) and Doordarshan (DD). Now it has been representing one of the largest domestic communication satellites systems in Asian-Pacific region providing about 175 transponders in C, Ku and S frequency bands. INSAT space segment consists of twenty four satellites out of which eleven satellites such as INSAT-2E, INSAT-3B, INSAT-3C, KALPANA-1, INSAT-3A, GSAT-2, INSAT-3E, EDUSAT, INSAT-4A, INSAT-4B, and INSAT-4CR are presently in service (Table 6.5). Satellites of INSAT series are monitored and controlled by master control facilities at Hassan and Bhopal. Satellites of INSAT series are commonly placed at an altitude of about 36,000 km above equator in the geostationary orbit. As a consequence, they remained at a fixed position relative to Earth.

Bhopal. Satellites of INSAT series are commonly placed at an altitude of about 36,000 km above equator in the geostationary orbit. As a consequence, they remained at a fixed position relative to Earth.

Table 6.5: Communication satellites of India (after overview of Indian space sector, 2010).

S. No.	Spacecraft	Launch date	Launch vehicle	Mission Status
1.	APPLE	19th June, 1981	Ariane-1	Completed
2.	INSAT-1A	10th April, 1982	Delta	Failed after 5 months
3.	INSAT-1B	30th August, 1983	Space shuttle	Completed
4.	INSAT-1C	21st July, 1988	Ariane-3	Failed after 2.5 years
5.	INSAT-1D	12th June, 1990	Delta	Completed
6.	INSAT-2A	10th July, 1992	Ariane-4	Completed
7.	INSAT-2B	23rd July, 1993	Ariane-4	Completed
8.	INSAT-2C	7th December, 1995	Ariane-4	Completed
9.	INSAT-2D	4th June, 1997	Ariane-4	Failed after 4 months
10.	INSAT-2E	3rd April, 1999	Ariane-4	In operation
11.	INSAT-3B	22nd March, 2000	Ariane-5	In operation
12.	GSAT-1	18th April, 2001	GSLV-D1	Completed
13.	INSAT-3C	24th January, 2002	Ariane-4	In operation
14.	KALPANA-1	12th September, 2002	PSLV-C4	In operation
15.	INSAT-3A	4th April, 2003	Ariane-5	In operation
16.	GSAT-2	28th September, 2003	GSLV-D2	In operation
17.	INSAT-3E	28th September, 2003	Ariane-5	In operation
18.	EDUSAT	20th September, 2004	GSLV-F1	In operation
19.	HAMSAT	5th May, 2005	PSLV-C6	Completed
20.	INSAT-4A	22nd December, 2005	Ariane-5	In operation
21.	INSAT-4C	10th July, 2006	GSLV-F2	Launch failed
22.	INSAT-4B	12th March, 2007	Ariane-5	In operation
23.	INSAT-4CR	2nd September, 2007	GSLV-F4	In operation
24.	GSAT-4	15th April, 2010	GSLV-D3	Not placed in orbit

Check Your Progress I

Spend 5 mins

1) How many remote sensing satellites have been launched by ISRO?

....

....

....

2) Write about the uses of IRS and INSAT series.

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6.4 GLOBAL SPACE PROGRAMMES

A number of remote sensing satellites have been launched by various space organisations of the world to collect remote sensing data. USA, European Union, Russia, Japan, China and Canada are leading countries in Earth observation satellite programmes. Let us now discuss about the important international remote sensing satellite programmes.

6.4.1 Landsat

Landsat satellite system is a joint venture of NASA and U.S. Geological Survey (USGS) to gather Earth resource data using a series of satellites. It is an unmanned system that was originally called ERTS (Earth Resources Technology Satellite) and later its name was changed to Landsat in 1974. Up to now seven Landsat satellites have been launched (Table 6.6). NASA operated Landsat system through early 1980s, but in January 1983 responsibility for operating the system was transferred to commercial division of the National Oceanic and Atmospheric Administration (NOAA). In October, 1985, Earth Observation Satellite Company (EOSAT) took responsibility of operating Landsat-4 and 5. According to the Land Remote Sensing Policy Act of 1992, Landsat programme returned to the Government under joint management of U.S. Department of Defence and NASA. Landsat programme management structure changed repeatedly from 1992 through 1998. As a result, USGS assumed operational responsibility for Landsat programme in 1999 and NASA continued flight operations for Landsat-7.

Table 6.6: List of Landsat series of satellites launched by USA

Satellite	Launched	De-commissioned	Sensors
Landsat-1	23rd July, 1972	January 6, 1978	MSS and RBV
Landsat-2	22nd January, 1975	February 25, 1982	MSS and RBV
Landsat-3	5th March, 1978	March 31, 1983	MSS and RBV
Landsat-4	16th July, 1982	June 30, 2001	MSS and TM
Landsat-5	1st March , 1984	(Operational)	MSS and TM
Landsat-6	5th October, 1993	(Did not achieve orbit)	ETM
Landsat-7	15th April, 1999	(Operational)	ETM+

All Landsat satellites have flown in a sun-synchronous orbit. Out of seven Landsats, the first three (Fig. 6.8a) Landsat-1, 2 and 3 launched in 1972, 1975 and 1978, respectively, are known as first generation Landsats. They are placed at an altitude of 919 km with an inclination of 99°. Platform of these Landsats was a modified version of pre-existing Nimbus meteorological satellite. Multispectral Scanner (MSS) and Return-Beam Vidicon (RBV) were the imaging systems for these Landsats. Landsats orbited the Earth every 103 minutes, completing 14 orbits per day. It took 18 days and 251 overlapping orbits to provide almost complete coverage of the Earth's surface with 185 km image swaths. On the other hand Landsat-4 and 5 (Fig. 6.8b) belong to the second generation Landsats and consist of two Landsats launched in 1982 and 1984. MSS and a new improved Thematic Mapper (TM) were the main sensors in these Landsats. Landsat-4 and 5 placed at lower altitude about 705 km than Landsat-1 to 3. As a result, only 233 orbits and 16 days are required for Landsat-4 and 5 to cover the Earth. These satellites collected data over a 185 km swath.

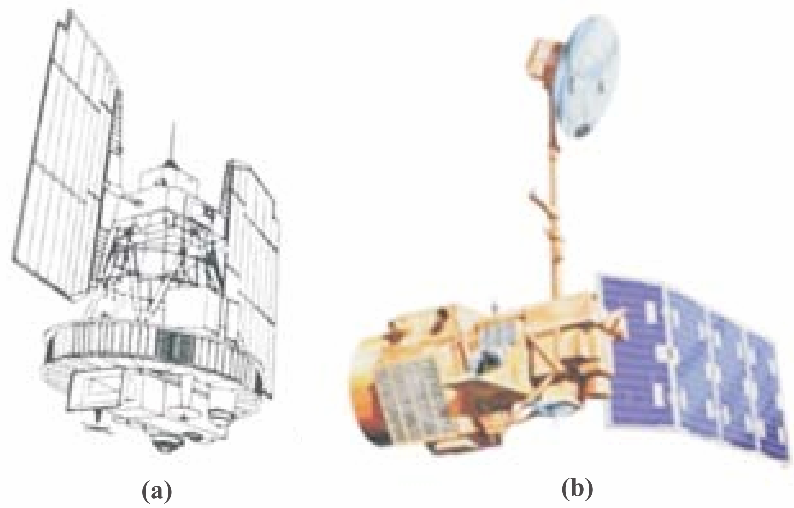


Fig. 6.8: (a) Schematics of Landsats-1 to 3 and (b) Landsat-5 (source: http://landsat.usgs.gov)

Launch of Landsat-6 failed because satellite did not achieve required orbital position. It was equipped with the first version of the Enhanced Thematic Mapper (ETM) sensor which had new capability of imaging in a 15x15 m panchromatic band as well as in other 7 spectral bands. Landsat-7 was successfully launched in 1999. It is placed at an altitude of 705 km above the Earth. The payload of Landsat-7 is a single nadir pointing instrument which is called Enhanced Thematic Mapper Plus (ETM+). ETM+, the successor of TM, records data in scan line corrector (SLC) mode (Fig. 6.9a). Unfortunately, SLC mode of ETM+ failed in 2003 and subsequent efforts to recover SLC were not successful. Without an operating SLC, ETM+ line of sight now traces a zig-zag pattern along the satellite ground track (Fig. 6.9b). As a result, imaged area is duplicated with width that increases toward the scene edge and about 22% of any given scene is lost because of this failure.

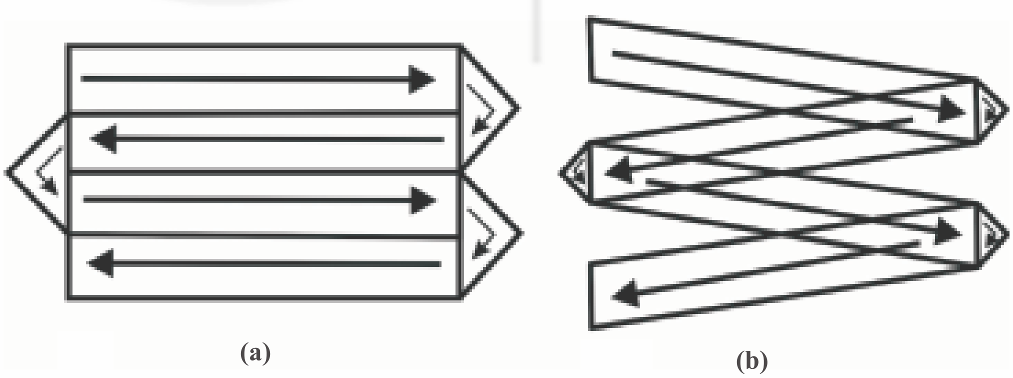


Fig. 6.9: (a) Scan line corrector mode of Landsat-7 and (b) failure of SLC (source: www.landsat.usgs.gov)

Data gathered by Landsats have extensively been used by government, commercial, industrial and educational institutions over the globe. The changes in agricultural areas, deforestation, natural disasters, desertification, urbanisation and degradation of water resources can be monitored with the Landsats data. Characteristics of Landsat sensor system are given in Table 6.7.

Table 6.7: Landsat sensor system characteristics

S. No.	Sensor type	Band	Spectral resolution (µm)	Spatial resolution (m)
1.	**Multispectral Scanner (MSS)**	1	0.5-0.6 (green)	80
		2	0.6-0.7 (red)	80
		3	0.7-0.8 (red - NIR)	80
		4	0.8-1.0 (NIR)	80
2.	**Thematic Mapper (TM)**	1	0.45-0.52 (blue)	30
		2	0.52-0.60 (green)	30
		3	0.63-0.69 (red)	30
		4	0.76-0.90 (NIR)	30
		5	1.55-1.75 (mid-IR)	30
		6	10.4-12.5 (thermal-IR)	120
		7	2.08-2.35 (mid-IR)	30
3.	**Enhanced Thematic Mapper (ETM+)**	1	0.450-0.515 (blue)	30
		2	0.525-0.605 (green)	30
		3	0.630-0.690 (red)	30
		4	0.750-0.900 (NIR)	30
		5	1.55-1.75 (mid-IR)	30
		6	10.4-12.5 (thermal-IR)	60
		7	2.08-2.35 (mid-IR)	30
		PAN	0.52-0.90 (visible-IR)	15

6.4.2 SPOT

SPOT (Satellite Pour l'Observation de la Terre) programme consists of a series of high-resolution optical remote sensing satellites. This series is being developed and operated by the French Space Agency, Centre National d'Etudes Spatiales (CNES). The primary mission of this programme is to obtain Earth imagery for landuse, agriculture, forestry, geology, cartography, regional planning, water resources and GIS applications. Five SPOT satellites have been launched since 1986, which are providing medium to high resolution images of the Earth's surface. The SPOT satellites are in a sun-synchronous orbit at an altitude of about 810 km. SPOT-1 satellite was launched on 21st February, 1986. It had a spatial resolution of 10 × 10 m in panchromatic and 20 × 20 m in multispectral mode. SPOT-2 and 3 having same payloads as that of SPOT-1, were launched on 22nd January, 1990 and 25th September, 1998, respectively. SPOT-1, 2, and 3 are all identical and consist of a multipurpose platform known as SPOT bus, two identical High Resolution Visible (HRV) sensors and a package of data recorders and transmitter. HRV sensors operate in both panchromatic and multispectral modes. Thus, spectral resolution of SPOT-1 to 3 is not as good as that of the Landsat TM. SPOT-3 mission failed in November, 1996, but 1 and 2 are still operational.

SPOT-4 successfully launched in March 1998 and has similar features to that of the previous satellites. But it has additional spectral Short Wave Infrared (SWIR) band equivalent to TM band 5 of Landsat dedicated for vegetation and soil moisture applications. It is equipped with two High Resolution Visible Infrared (HRVIR) push-broom imaging sensors. Each HRVIR had a swath width of 60 km. HRVIR was derived from HRV sensors of SPOT-1 to 3. SPOT-4 provided 10 m spatial resolution in the panchromatic band and 20 m resolution in the multispectral bands. SPOT-5 was launched in May, 2002 and is the most innovative satellite of the series. It is equipped with High Resolution Stereoscopic (HRS), High Resolution Geometry (HRG) and Vegetation sensors. The new HRS and HRG instruments derived from the HRVIR instrument of SPOT-4 which offers high resolution in across-track direction with 2.5 m resolution in panchromatic mode and 10 m in the visible and NIR ranges. Different characteristics of SPOT sensor system are given in Table 6.8.

Table 6.8: SPOT sensor system characteristics

S.No.	Sensor type	Band	Spectral resolution (µm)	Spatial resolution (m)
1.	High-resolution visible (HRV) for SPOT-2 and -3	1	0.50-0.59 (green)	20
		2	0.61-0.68 (red)	20
		3	0.79-0.89 (NIR)	20
		PAN	0.51-0.73 (visible-IR)	10
2.	High-resolution visible-infrared (HRVIR) for SPOT-4	1	0.50-0.59 (green)	20
		2	0.61-0.68 (red)	20
		3	0.78-0.89 (NIR)	20
		4	1.58-1.75 (mid-IR)	20
		PAN	0.61-0.68 (red)	10
3.	HRVIR for SPOT-5	1	0.50-0.59 (green)	10
		2	0.61-0.68 (red)	10
		3	0.78-0.89 (NIR)	10
		4	1.58-1.75 (mid-IR)	20
		PAN	0.51-0.73 (visible-IR)	5
4.	Vegetation for SPOT-4 and 5	1	0.43-0.47 (blue)	1000
		2	0.61-0.68 (red)	1000
		3	0.78-0.89 (NIR)	1000
		4	1.58-1.75 (mid-IR)	1000

6.4.3 RADARSAT

RADARSAT is the first sophisticated Earth observation satellite of Canada. It was built under the management of Canadian Space Agency in co-operation with provincial governments and private sector. Until now two RADARSATs have been launched. RADARSAT-1 was launched in 1995 by NASA on a Delta II rocket. It was placed into a near polar sun-synchronous orbit at an altitude of 798 km above the Earth at an inclination of 98.6°. It orbits the Earth 14 times per day in which each orbit takes 100.7 minutes to complete.

RADARSAT-1 has dawn-dusk orbit which enable it to cross the equator at dawn and dusk, i.e. 6.00 a.m. and 6.00 p.m. of local time. Further, this orbit keeps solar cell arrays of the satellite in almost continuous sunlight and ensures satellite to rely on solar energy rather than battery power. It is equipped with an advanced single C-band radar sensor SAR. RADARSAT SAR is a powerful microwave instrument which transmits a microwave energy pulse in C-band having 5.3 GHz frequency to the Earth. SAR measures the amount of energy that is reflected back to the satellite from the Earth's surface. It has a wide variety of beam widths which can capture swaths from 45 to 500 km with resolution from 8 to 100 m and at incidence angles from 10° to 60°.

RADARSAT-1 is horizontally polarised in which microwaves travel horizontal to the Earth's surface (Fig. 6.10a). It has seven images sizes namely fine, standard, wide, scanSAR narrow, scanSAR wide, extended low and extended high which are collectively termed as beam modes (Fig. 6.11). As a consequence, it provides a range of spatial resolution and geographic coverage.

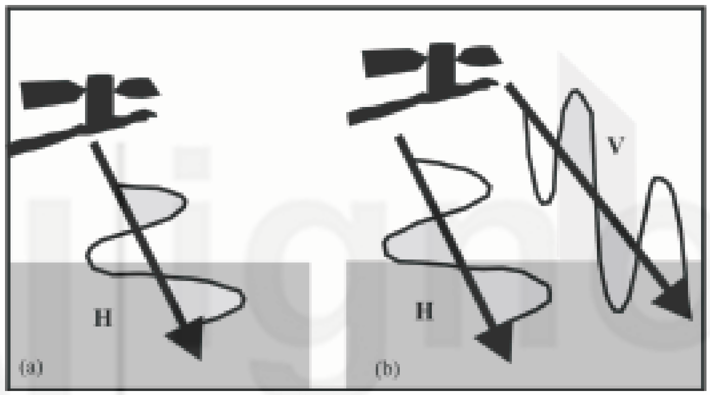


Fig. 6.10: (a) Horizontal polarisation in RADASAT-1 and (b) both horizontal and vertical polarisation in RADARSAT-2. H – horizontal and V – vertical (source: www.asc-csa.gc.ca)

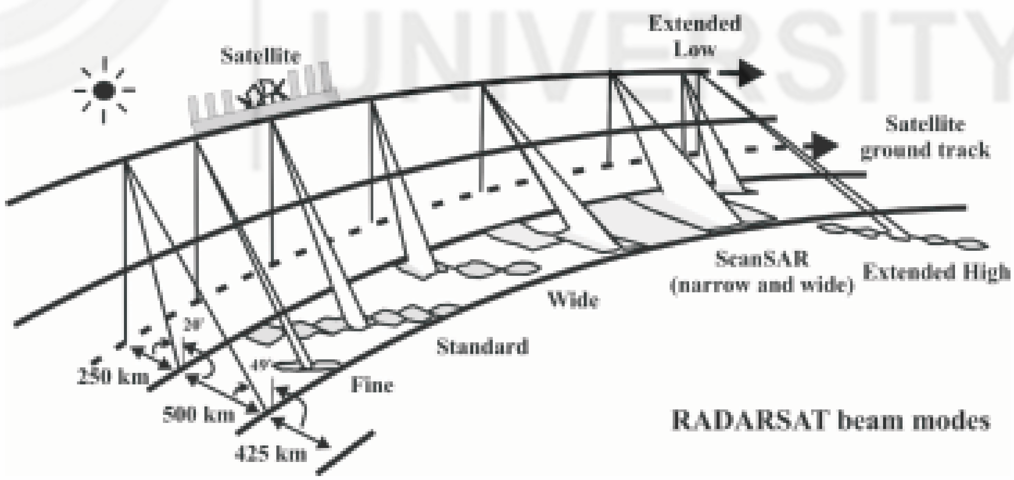


Fig. 6.11: RADARSAT-1 imaging modes (source: www.asc-csa.gc.ca)

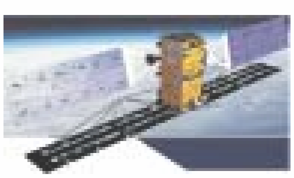


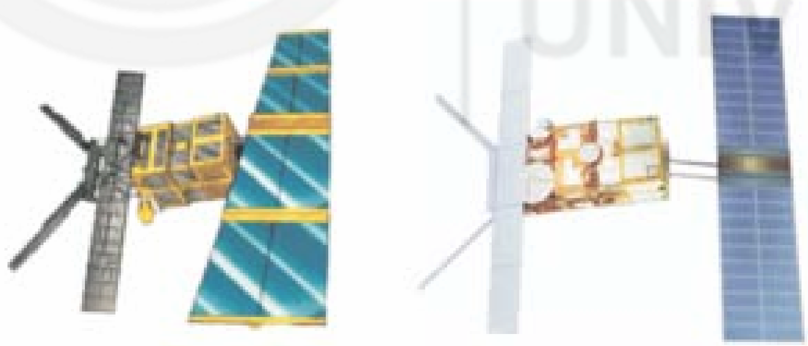
Fig. 6.12: RADASAT- 2 satellite (source: www.asc-csa.gc.ca)

The world's most advanced commercial C-band SAR satellite RADARSAT-2 was launched in 2007 (Fig. 6.12). It retains many specifications of RADARSAT-1 (e.g., imaging modes and orbital parameters). But some significant modification of RADASAT-2 made it a premier Earth observation radar remote sensing system. These modifications include 3 m high resolution imaging, both horizontal and vertical polarisation imaging modes (Fig. 6.10b), left and right looking imaging options, superior data storage and onboard GPS receivers for monitoring satellite position.

RADARSAT supply data to monitor environmental changes and natural resources of Earth at national as well as global level. It also provides important information in the fields of agriculture, hydrology, cartography, forestry, oceanography and coastal monitoring for both scientific and commercial users.

6.4.4 European Remote Sensing Satellites

European Remote Sensing satellite (ERS) is a European programme for Earth observation sponsored by the European Space Agency. Under this programme two satellites ERS-1 and ERS-2 (Fig. 6.13) have been designed and developed to observe oceans and its circulation, sea ice distribution, sea surface wind and land areas with high resolution radar. ERS-1 was launched in July, 1991. It is placed in sun-synchronous polar orbit at an altitude of about 785 km at an inclination of 98.5°. It has a ground swath width of 100 km. It is equipped with a comprehensive payload including an imaging C-band SAR, radar altimeter, wind scatterometer, along-track scanning radiometer, micro-wave sounder and other powerful instruments to measure ocean surface temperature and winds at sea. During 1995, ERS-2 was launched which represents a follow-on mission of ERS-1. ERS-2 is identical to ERS-1 but it is provided with an additional sensor to monitor atmospheric ozone levels. There is about 30 minutes time lag between ERS-1 and ERS-2, in the same orbital plane as a consequence a one day interval between ERS- 1 and ERS-2 is observed on the same ground swath. Both ERS-1 and ERS-2 were operated in tandem from August, 1995 to May, 1996 to provide image pairs for SAR interferometry research. In March, 2000, ERS-1 satellite finally ended its operations but ERS-2 is expected to continue operating for several more years.



(a) **(b)**

Fig. 6.13: (a) ERS-1 and (b) ERS-2 (source: www.esa.int)

6.4.5 Japanese Earth Resource Satellites

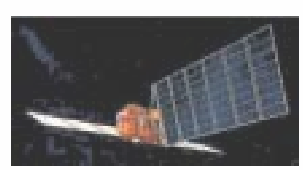


Fig. 6.14: JERS-1 satellite (source: www.jaxa.jp)

National Space Development Agency (NASDA) of Japan launched the Japanese Earth Resource Satellite, JERS-1 in 1992 (Fig. 6.14). JERS-1 (*FUYO-1in Japanese*) is an advanced Earth observation satellite which is jointly developed by NASDA and the Ministry of International Trade and Industry (MITI), Japan. NASDA developed satellite bus, while MITI built

JERS-1 gathered data on global land masses which have great applications in the fields of land surveys, agriculture, forestry, fisheries, environmental management, disaster prevention, coastal surveillance and for locating natural resources.

Check Your Progress II

1) SPOT-1 satellite had a spatial resolution of .... in panchromatic and .... in multispectral mode.

2) JERS-1 had a spatial resolution .... in cross-track and .... in along-track direction.

6.5 COMMERCIAL REMOTE SENSING SATELLITES

Recently, some high resolution Earth observation satellites have been launched by commercial operators such as DigitalGlobe, GeoEye, ImageSat International and Leica Geosystems. Let us now discuss about some of the successful commercial satellites.

Spend 5 mins

6.5.1 QuickBird

QuickBird (Fig. 6.15) is a remote sensing satellite of DigitalGlobe which is a commercial imagery provider company with headquarters located at Longmont, Colorado, USA. Up-to-date DigitalGlobe launched four commercial satellites namely - EarlyBird-1, QuickBird, WorldView-1 and WorldView-2 in December, 1997, October, 2001, September, 2007, and October, 2009, respectively. DigitalGlobe lost communication with EarlyBird-1 after four days of its launching. But other satellites are functioning successfully.

QuickBird represents first satellite in a constellation of sub-meter spacecraft that developed by DigitalGlobe. It offers a unique highly accurate and commercial high resolution imagery of Earth. It was launched on 18th October, 2001 by Boeing Delta II launch vehicle into a 600 km orbit. It has a swath width of 20 to 40 km. It offers images with 0.61 × 0.61 m panchromatic and 2.44 × 2.44 m multispectral spatial resolution. Its revisit time ranges from 1 to 5 days. It is the fourth satellite which obtains highest resolution commercial imagery of Earth after WorldView-1, WorldView-2 and GeoEye-1. It has a greatest capacity of on-board storage of data than any other satellites. It is capable of acquiring more than 75 million km^2 of imagery data yearly and also allowing DigitalGlobe to update its image library at rapid speed. The high quality satellite imagery of QuickBird is commonly used for map creation, change detection and image analysis.

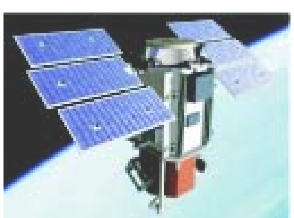


Fig. 6.15: Quickbird satellite (source: www.digitalglobe.com)

6.5.2 IKONOS

IKONOS is a satellite of GeoEye Inc. (formerly known as ORBIMAGE or Orbital Imaging Corporation) which is a commercial imagery provider company located in Herndon, Virginia, USA. GeoEye Inc. has launched IKONOS, OrbView-2 (SeaStar), OrbView-3 and GeoEye-1 satellites in 1999, 1997, 2003 and 2008, respectively. The first IKONOS was launched on 27th April, 1999 but unfortunately, it never achieved its orbit. Subsequently, a second IKONOS was launched successfully on 24th September, 1999.

The IKONOS is in a sun-synchronous 681 km orbit with an inclination 98.1°. The orbit provides daily access to regions within 45° of nadir, 3 day revisit within 26° of nadir and 141 day revisit within 1° of nadir. The satellite provides imagery with spatial resolution of 1 × 1 m in panchromatic band and 44 m in multispectral bands. One meter colour imagery can be created by merging IKONOS's panchromatic and multispectral imageries. In addition, the satellite has both cross-track and along-track sensors which allow it to acquire data flexibly having frequent revisit capability. Satellite collects data at a rate of over 2,000 km^2/m. As a result, it has collected over 250 million km^2 of imagery of Earth surface digitally. High spatial resolution imagery collected by IKONOS is being largely used for national security, military mapping, Earth resources management, air and marine transportation, and city and urban planning.

6.5.3 OrbView

OrbView is another group of satellites belonging to GeoEye. Four OrbView satellites have been launched by GeoEye. OrbView-1 was launched in April, 1995. It is an atmosphere monitoring satellite that provided weather data to NASA. Following this, GeoEye launched OrbView-2 in August, 1997. It provides images of oceans which are useful for the study of global warming, commercial fishing, environmental and coastal monitoring. In June 2003, the third satellite of the series, OrbView-3 was launched successfully. OrbView-4 was launched in September, 2001 but this satellite failed to reach required orbit.

OrbView-3 was designed to provide high resolution imagery of the Earth (Fig. 6.16). It was successfully launched on 26th June, 2003. This satellite is equipped with a camera to take images with 1 × 1 m in panchromatic and 4×4 m in multispectral spatial resolution at a swath width of 8 km. It is in a 470 km sun-synchronous orbit with an equatorial crossing time of 10.30 a.m. The sensor revisits locations on Earth in less than three days. OrbView-3 is the first commercial satellite to supply high resolution imagery from space. Therefore, the imageries collected by it can be used for environmental monitoring, construction planning, precise mapping and intelligence gathering.

6.6 SUMMARY

In this unit, you have studied about:

- Remote sensing satellites which are being operated by various countries. Notably among them are IRS series, CARTOSATs and RISAT of ISRO, India; Landsat of NASA and USGS, USA; SPOT of FSA, France; RADARSAT of CSA, Canada; ERS of ESA, Europe; JERS-1 of NASDA, Japan and commercial satellites such as QuickBird of DigitalGlobe, and IKONOS and OrbView-3 of GeoEye.

- Remote sensing satellites equipped with improved sensor systems are placed in a sun-synchronous orbit with difference in altitude above the Earth (average altitude is 900 km). They record imagery of the Earth at different spatial, temporal and spectral resolutions.

- Under IRS series of ISRO, India has launched 18 remote sensing satellites. Data gathered from IRS series is received, processed and disseminated from NRSC, Hyderabad. It is extensively used for monitoring of crops health, drought conditions, forest covers, natural resources; land use and land cover mapping; disaster management and sustainable development of the country. CARTOSAT data is mostly used for cartography and a host of other applications.

- India has made tremendous progress in the field of communication by launching 24 satellites under the INSAT series of ISRO. Out of 24, eleven are active and giving continuous service. Satellites of INSAT series are providing indigenous services in telecommunications, broadcasting, meteorology, and search and rescue operations in India.

- Quickbird has highest resolution which is followed by IKONOS and OrbView-3. But Landsat and SPOT are the more popular groups of satellites than others because these satellites are extensively used as they also provide wide spectral range.

- A group of advanced Earth observation satellites such as RISAT, RADARSAT, ERS-1 and 2, and JERS-1 operating in C and L-band frequency of microwaves have been launched. These satellites equipped with active sensors, record 24 hours data of the Earth during day and night and they also include regions covered by clouds, snow and ice.

6.7 UNIT END QUESTIONS

1) Discuss Earth resource remote sensing satellites.
2) Differeniate between IRS and INSAT series of satellites.
3) Discuss RADARSAT.

6.8 REFERENCES

- http://landsat.usgs.gov.
- www.asc-csa.gc.ca.
- www.digitalglobe.com.
- www.esa.int.
- www.geoeye.com.
- www.isro.org.
- www.jaxa.jp.

Spend 30 mins

All the above websites were retrieved between 15 May, 2011 and 30 June, 2011.

6.9 FURTHER/SUGGESTED READING

- Gupta, R. P., (2003), *Remote Sensing Geology,* 2nd Ed., Springer-Verlag, Berlin.

- Jensen, J. R., (2009), *Remote Sensing of the Environment – An Earth Resource Perspective*, 2nd Ed., Dorling Kinderslay India Pvt. Ltd, New

Delhi.

- Joseph, G. (2005), Fundamentals of Remote Sensing, University Press (India) Pvt. Ltd, hyderabad.

6.10 ANSWERS

Check Your Progress I

1) 18

2) IRS is being used to record earth's resources data. INSAT is being used for communication, television broadcasting, weather monitoring and weather forecasting.

Check Your Progress II

1) 1010 m in panchromatic and 2020 m multispectral.

2) 18.3 m in cross-track and 24.2 m in along-track.

Unit End Questions

1) It includes all man-made staellites which are used to study the Earth's surface to explore its natural resources and other phenomena useful to humans. These are placed in sun-synchronous orbit so that they can take repeated images of a location.

2) Refer to subsections 6.3.1 and 6.3.3.

3) Refer to section 6.4.3.

GLOSSARY

Band: A wavelength interval in the electromagnetic spectrum. For example, in Landsat by non-photographic methods.

C-band: The region of radar wavelength from 4 - 8 cm.

Contrast: The ratio between the energy emitted or reflected by an object and its immediate surroundings.

Detectability: The ability of a remote sensing system to record the presence or absence of a feature on the landscape

GPS: The Global Positioning System (GPS) is a satellite-based navigation system made up of a network of 24 satellites placed into orbit by the U.S. Department of Defence.

Ground resolution cell: Area on the terrain that is covered by the IFOV of a detector.

Ground swath: The width of the strip of terrain that is scanned by a sensor system.

Image: Pictorial representation of a scene recorded by a remote sensing system. Although image is a general term, it is commonly restricted to representations acquired images the bands designate specific wavelength intervals at which images are acquired.

Instantaneous field of view (IFOV): Solid angle through which a detector is sensitive to radiation. In a scanning system, the solid angle subtended by the detector when the scanning motion is stopped.

Laser altimeter: Laser altimeter is an instrument that measures the height or elevation of the terrain from an aircraft or a satellite.

L-band: The region of radar wavelength from 15 to 30 cm.

MSS: The multispectral scanner of Landsat that acquires images at four wavelength bands in the visible and reflected infrared regions.

Noise: Random or repetitive events that obscure or interfere with the desired information.

Orbital period: The orbital period is the time taken for a given object to make one complete orbit about another object.

Passive remote sensing: Uses natural energy, either reflected sunlight or emitted thermal or microwave radiation

Radar: Radar is an object-detection system which uses electromagnetic waves specifically radio waves to determine the range, altitude, direction, or speed.

Recognisability: The ability of the human interpreter to identify a feature detected by the sensor but may not be recognisable (e.g., narrow straight lines in an image may be roads, railways, or canals).

Resolution cell: The cell defined by the resolutions in the range and azimuth directions (does not mean the same thing as pixel). Pixel sizes need not be the same thing. This is important since (i) the independent elements in the scene are resolutions cells, (ii) neighbouring pixels may exhibit some correlation.

Resolution: Ability to separate closely spaced objects on an image or photograph. Resolution is commonly expressed as the most closely spaced line-pairs per unit distance that can be distinguished.

Round Trip Time (RTT): In a satellite network, Round Trip Time (RTT) is the time required for a signal to travel from a terrestrial system up to the satellite and back, or for a signal to travel from a satellite down to a terrestrial system and back up to the satellite again.

Satellite: An object revolving around earth or any planet. Man-made satellites are called artificial satellites e.g. IRS-1A. Other satellites are called natural satellites e.g. Moon.

Scatterometer: A calibrated radar that measures the scattering properties of a surface and it is designed for back scatter measurements

Spectral reflectance: Reflectance of electromagnetic energy at specified wavelength intervals.

Stratosphere: The stratosphere is the second major layer of Earth's atmosphere.

Swath: It is the area imaged on the surface by the sensor.

TM: A cross-track scanner of Landsat that records seven bands of data from visible to the thermal infrared regions.

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