OVERVIEW OF REMOTE SENSING

Introduction

Remote sensing is defined as the science which deals with obtaining information about objects on earth surface by analysis of data, received from a remote platform. Usually the term ‘remote sensing’ is used to define identification of earth features by analysis of electromagnetic radiation, which is reflected/emitted by the earth surface. Every object reflects/ scatters a portion of the electromagnetic energy/incident on it depending upon its physical properties. In addition, objects emit radiation depending on their temperature and emissivity. If we study the reflectance/ emittance by an object in different wavelengths, we get a reflectance/ emittance pattern, which is characteristic of that object known as ‘spectral signature’. Judicious interpretation of the spectral signature leads to the identification of the features on the earth surface.

Electro Magnetic Spectrum (EMS)

Electro Magnetic Spectrum is array of all electromagnetic radiation that moves with velocity of light, characterized by wavelength or frequency. The optical wavelengths (0.3 to 15 micrometer) are the ones most useful in remote sensing. Energy at these wavelengths can be reflected and refracted with solid materials like, mirrors and lenses.

The region between 0.38 and 3.0 micrometer is frequently termed as reflective portion of the spectrum as the energy sensed incident upon it. This is further divided into two parts - visible (0.38 to 0.72 μm) wavelengths and reflective infrared wavelength (0.72 to 3.0 æm). Electromagnetic energy in wavelengths 7.0 to 15.0 μm is in far infrared and called thermal infrared.

Atmospheric Windows

The atmosphere of the earth has a degrading, stopping effect on the solar radiation reaching the earth's surface, as the earth's atmosphere is transparent to electromagnetic radiations only in small parts. The spectral bands of least attenuation are called windows. Important windows for remote sensing occur throughout the spectrum but the optical wavelengths extending from 0.3 to 15 micrometers are of the greatest use in remote sensing.

Principles Of Remote Sensing

Detection and discrimination of objects or surface features means detecting and recording of radiant energy reflected or emitted by objects or surface material. Different objects return different amount and kind of energy in different bands of the electromagnetic spectrum, incident upon it. This unique property depends on the property of material (structural, chemical, and physical, surface roughness, angle of incidence, intensity, and wavelength of radiant energy).

Remote sensing can be either passive or active. Active systems have their own source of energy whereas the passive systems depend upon the solar illumination or self emission for remote sensing.

As already indicated different objects behave differently and return different amount and kind of energy in different bands of the electromagnetic spectrum incident upon it. Spectral response of each object within the wavelength region 0.3 to 20 micrometer range is unique and can be used for identification or discrimination of objects just as signatures are used to discriminate different persons. Thus the measurement of variation in spectral response enables identification and/or discrimination of different objects. The variation in spectral response can be due to either spectral variation (due to wavelength), spatial variation (due to shape, size, colour, location etc.,) and temporal variation (due to time) or combination of any of these factors. In remote sensing detecting these differences enables identification of ground objects from air or from space. By dividing the spectrum into number of bands and separately obtaining the responses there from, the uniqueness of spectral signature of any of confidence of recognition.

Thus, the identification of materials/objects through remote sensing involves:

- Detection and measurement of variation in electromagnetic spectrum- Data Acquisition

- Correlation of measurements to know objects or surface materials- Data Interpretation and Analysis.

Spectral Responses Of Different Surface Materials

Three most familiar earth surface materials are soil, water and vegetation. For each material, reflectance varies with the wavelength. In case of soils, the reflectance depends upon number of factors such as colour, surface condition, moisture, organic matter and, vegetation. Comparison of dry and moist soil clearly indicates that moist soils have lower reflectance than dry soils and exhibit the effects of water absorption bands.

In case of water, there is distinct decrease in reflectance from visible to infrared wavelengths. This is observed both in clear and turbid waters.

In case of vegetation, low reflectance is observed in blue and red part of visible spectrum due to chlorophyll absorption but the reflectance is high in green part. The shape of curve in visible wavelength is determined by leaf pigmentation. In near infrared, there is sharp increase in the reflectance, giving very bright tone on the image.

However, in nature these generalized curves vary in many ways and for many reasons. For example, moist soil reflects differently than dry soil; a crop on good soil appears differently from same crop on poor soil. Moreover the spectral response is not static but varies with time. Thus, it is imperative to understand physical and biological reasons for variations in reflectance for effective analysis of data.

Multispectral Approach

It is also quite evident that the spectral response varies with the wavelength and it is possible to discriminate certain objects even though they may have same or similar reflectance characteristics in some part of spectrum, by acquiring spectral information in other part of spectrum. For example, if data is acquired in three wavelength, by plotting spectral responses in three dimensional space, objects similar in nature tend to form clusters which aid in their identification and discrimination from other objects. This is called multispectral approach and found to be very useful in differentiating objects or surface materials which tend to have almost similar spectral response.

As already discussed, Remote Sensing is defined as the collection of information about an object without being in physical contact with it. This information can be in analogue or digital form. In conventional aerial remote sensing (Aerial Photography) this information is recorded in the form of photographic images where different lens/film/filter combinations perform as sensors. In satellite remote sensing, the information is recorded through a more sophisticated system of various types of scanners/ detectors/ electronic recorder combinations and the data is stored on computer compatible tapes (CCT) in digital form for its use later. Before information could be extracted from such raw data, it is corrected for geometric and radiometric errors. It is, therefore, inevitable that such voluminous data is processed and analyzed through computers.

Aerial Remote Sensing

Aerial photography is the most commonly used form of remote sensing and is widely used for topographic mapping, surveys for geological, soil and forestry mapping, engineering, town planning and environmental surveys. Aerial photography (or aerial remote sensing) is a form of remote sensing where instead of space borne platforms, an airborne platforms like Aircraft (also balloon and helicopters) is used with aerial cameras along with their various lens and films combinations, to record and store information in the form of photographic images. Such aerial photography has applications in various fields as source of data, which can be analyzed quantitatively as well as qualitatively.

Aircraft And Cameras

In the beginning, cameras were carried aloft by balloons and even now balloons are sometimes used. However, most of the aerial remote sensing is now done from aeroplanes. Helicopters have the advantage of being able to fly at low altitudes and at slow speeds, whereas aeroplanes can fly at faster speeds and at greater heights, thereby covering large areas in less time. In our country today for remote sensing we have aircraft available with an operational altitude ceiling of about 40,000 feet.

When we mention camera as a sensor it may be a video camera, enabling us to convert the image to an electronic signal, or the image may be recorded on photographic film directly. In case of photographs on a film, the wavelengths of the electromagnetic energy spectrum used are those that can be recorded on a photographic film, i.e. from 400 nm (violet) to 900 nm (near IR). Further, a camera gives the momentary image of the whole ground scene onto the image plane, as perspective projection. The scale of the picture obtained is f/H, where f is the focal length of the lens and H is the height above ground. Thus the scale of an image can be varied by changing the flying height, or by changing to a lens of different focal length. Different colour filters can be mounted in front of the lens to suit the requirements when different types of films are used. In multispectral cameras, the same ground scene is received on film (through different lenses, usually four, with Blue, Green, Red and IR filters). These images, which are originally in black and white when viewed through colour filters in an additive colour viewer, provide a true colour or false colour image of the ground scene.

Factors AffectingThe Type Of Aerial Photographic Task

The following factors influence the aerial photographic tasks.

- Scale
- Type of camera and lens
- Type of film and filters used
- Time/season of photography
- Direction of camera tilt
- Stereoscopic coverage, forward and side overlaps

Commonly used scale in aerial photography and their applications are as follows-

Scale	Usefulness
1:80,000	Regional Planning & special purpose mapping
1:50,00	Semi-detailed geologic mapping Reconnaissance for soil and forestry
1:25,000	Semi-detailed to detailed mapping for geology, forestry and soil
1:10,000	Detailed mapping for geology, soil detailed forestry surveys for species identification and timber volume estimation
1:5,000	Large scale surveys, site layouts, Urban area surveys, cadastral mapping

Procedure of Obtaining Aerial Photographs

For acquiring aerial photography, (both already existing or freshly flown) the users should write to Survey of India or National Remote Sensing Agency at the following address:

- Director
  National Remote Sensing Agency
  Balanagar, HYDERABAD - 500 037

- Officer-in-charge
  No.73 (APFPS) Party, Survey of India
  West Block No.4, Wing No.4, 2nd Floor
  R.K.Puram, NEW DELHI - 110 066

Remote Sensing Data From Satellite

Remote Sensing instruments mounted in satellites use a technology of carrying out fast and repetitive inventorying, mapping, and monitoring of several kinds of renewable and nonrenewable natural resources. Satellites provide a repetitive coverage capability. Data received at Earth Station, is recorded on high density digital tapes, and is processed through high speed interactive computers. Results are displayed as visuals on colour monitor screen, or as pictures, maps, tables, graphs, histograms etc. The data can be put through special signal processing techniques in order to bring out and emphasize certain hidden features.

Remote Sensing Satellites

As is known to us, many countries around the globe now have remote sensing satellite programs for land resources survey, environmental impact assessment, weather forecasting and ocean science studies. USA and USSR have made satellite building, launching and orbital tracking operational since 1960's. METSAT satellite programs for weather monitoring and LANDSAT satellite program for land resources surveys, both launched by the USA since 1960 and 1972 respectively, are well-known to us. These two series of satellite programs are providing good remote sensing data source and continuity of service to wide spectrum of world community for a long time. France has also started an ambitious 'SPOT' satellite series program with the launching of SPOT-1 on 22nd February, 1986. Japan has launched Marine Observation Satellite (MOS-1) on 19th Feb. 1987. RADARSAT is Chanda's first remote sensing satellite which is scheduled for launch during early 1990's. European Space Agency (ESA) has launched Earth Resources Satellite (ERS-1) in 1991. Later three satellite programs have microwave remote sensing payloads as `Workhorse' which will be very significant for resources inventory and environmental monitoring. India has launched, during the past 10 years, a number of experimental remote sensing satellites, notably amongst them, are Bhaskara-I (June, 1979) and Bhaskara-II (Nov., 1981), Indian Experimental Satellite for Earth Observation (SEO) series. With the experience gained in these programs through satellite and payload design and fabrication, satellite and launch vehicle integration, satellite orbital tracking data reception, processing and through several application verification programs, the Indian Remote Sensing

Satellites are planned to provide continuity of data service to remote sensing user community in India with improved sensor payloads, indigenous launching capability to be added to this space program. INSAT series of satellite, India's most ambitious multipurpose Geostationary satellite program, has among many sensors, (i) Very High Resolution Radiometer (VHRR) and (ii) Data Collection System (DCS) which are primarily dedicated to meteorological forecasting, but have some specific applications in hydrology, oceanography, and environmental studies.

Satellite Data Receiving Station

The Govt. of India authorized NRSA to set up a Satellite Receiving Station to receive digital data from LANDSAT series of Satellites launched by NASA/USA. This LANDSAT Receiving Station started functioning since January, 1980 situated at Shadnagar, 55 km. south of Hyderabad. The LANDSAT Earth Station has a coverage of nearly 2700 km. radius from its location on a repetitive basis and is capable of acquiring, tracking, receiving, recording, monitoring, processing and production of Landsat data. This Satellite Earth Station was augmented to receive data from TIROS-N series, the polar orbiting Meteorological satellites. For reception of SPOT Satellite data in India, a Memorandum of understanding was signed between "SPOTIMAGE" Corporation of France and NRSA, India. NRSA established SPOT data direct reception and processing facility at Shadnagar, Hyderabad and reception of SPOT data commenced in early 1987 and lasted till December, 1990. NRSA has also been given responsibility by the Department of Space, Govt. of India for data reception archival, data processing and dissemination functions from IRS series of satellites. The IRS Receiving Station at Shadnagar, Hyderabad is now receiving the data from IRS-1B satellite as per routine.

Data Acquisition Systems In Remote Sensing

In remote sensing, the data acquisition system can be broadly put in two main classes.

Photographic System. It includes all types of aerial cameras with different lens/film/filter combinations. Photographic cameras have been used both in manned and unmanned satellites during early stages, as well as some special programs like joint Indo-Soviet space flight, and U.S. Space Shuttle flight in 1983. The photographic films are sensitive in Visible and near Infrared region only.

Non-photographic Systems. Data products obtained by various scanner/detector/recorder combinations in analogue or digital form fall in this class. Scanner systems working beyond the visible and near infrared range of the electromagnetic spectrum, in thermal and microwave region (RADAR) are all non-photographic systems. Such data is collected by sensor system in satellite and transmitted to earth, where it is received and recorded at Ground Station.

Satellite data products are available in the following types of formats -

- High Density Digital Tape (HDDT)

- Quick Look Film
- Computer Compatible Tape(CCT), Digital Audio Tape(DAT)
- Compact Disc(CD-ROM)
- 70 mm film
- 240 mm Black and White film positive/negative in individual band.
- Black and White paper prints & enlargement in individual band
- 240 mm False Colour Composite (FCC) Film
- FCC paper print and enlargements

The Earth Station situated at Shadnagar, Hyderabad tracks the LANDSAT, METSAT, ERS and IRS series of satellites. The data is primarily recorded on HDDT. Standard products are generated from HDDTs and supplied to the users.

The NRSA Image Processing Laboratory located at NRSA, Balanagar, Hyderabad is the single repository of data supply in India on request to the users. The quality of the products, that leave NDC is checked in respect of computer processing, photographic reproduction, cloud cover and other defects as well. As an aid to the users for the selection of data, Browse Facility provides an array of computerized data listing, satellite coverage map, microfiche films and satellite orbital calendars.

All the user's data products requirements and inquiries can be addressed to-

Head, NRSA Data Centre,
National Remote Sensing Agency,
Balanagar, Hyderabad - 500 037 (A.P.).

Measurement, Analysis And Mapping Techniques Using Remote Sensing Data Products

In almost all remote sensing applications, the final task is usually the preparation of map. In case of Aerial Photographs, the technique of measurement and mapping is known as Photogrammetry. The mapping task involves plotting of various objects as identified in image, including their boundaries in well defined geometrical relationship with respect to their location on ground. The act of identifying various objects as imaged in the photograph or image is called Image Interpretation. In this manner, before a map is prepared, Image has to be interpreted to find out the objects of interest for mapping (i.e. to find out what has to be mapped). The act of mapping thus involves following steps -

- Interpretation of Image and identification of objects of interest.
- Measurement of image, plotting of details, and transferring the information on to the map sheet.

Analysis And Interpretation Of Remote Sensing Image Data

The images obtained from Remote Sensing are analyzed and interpreted, depending upon the characteristic of Image, and type of information required. When the Image is in the analogue (graphic) from, such as an `Aerial Photograph', it is interpreted by visual techniques. The Remote Sensing image in digital form are analyzed by using digital techniques on a computer. Visual Image interpretation techniques can be used for conventional aerial photograph as well as for colour composites. Most of the aerial photographic tasks are carried out at scale varying from 1:5,000 to 1:80,000. At these scales, ground resolution can be expected to be approximately 5 cm (at 1:5,000 scale aerial photography) to about 1 meter (at 1:80,000 scale aerial photography. With these value of ground resolution, most of the cultural objects on ground appear in identifiable shape on aerial photos. For their interpretation, their shape, size, tone (colour) texture, shadow, pattern and stereoscopic appearance are used as elements of image interpretation. The elements such as shape, size, tone etc. for various types of objects, in the photograph can be measured, and a comparison is made with the corresponding values on ground. By such comparison, the image can be correlated to a particular type of object and its physical characteristics, appearing on ground. For such type of analysis, some time ready made solutions (known as Interpretation keys) are also used.

In case of digital images, the darkness or brightness of a point (pixel or picture element) is recorded in the form of digital number, (from 0 to 255 in most cases), such that brightness of that points is in proportion to the magnitude of the number (known as Density value). In case of multispectral image, similar data is recorded in different spectral bands. Analysis of such a data is carried out by statistical manipulation of this data. Various type of digital image analysis work can be divided in three categories.

- Image Restoration
- Image Enhancement
- Image Classification

In case of image restoration, effort is made to restore the originality of image by applying geometric and radiometric correction. These corrections are necessary to remove the distortions, which take place because of the disturbances in atmospheric characteristics and deviations in the path and attitude of satellite in its orbit. For applying geometric corrections, some known Ground Control Points (GCP) and attitude data of satellite are used, while radiometric calibration data is used to correct for most of the radiometric corrections.

In case of Image enhancement visual quality of image is improved for better appreciation of image details. This is done by manipulating the image histogram and filtering and transformation of data. Various techniques of contrast stretching, spatial filtering, and principal component analysis are used to enhance the image details.

Image classification is the process of dividing an image into different classes based on spectral measurements. Computer oriented pattern recognition methods are used to establish decision rules for classifying image data. Image classification is a quantitative technique. Reflectance characteristics of different objects are studied and used to separate one object from another. These reflectance characteristics are referred to as spectral signatures of different types (classes) of objects on earth's surface (terrain features).

Terrain features that produce great spectral contrast are easy to identify. Larger changes in the image data correspond to changes in cover type, while subtle fluctuations indicate cover type subclasses and difficult conditions within each cover type. These factors result in spectral overlap between classes. Two types of methods are used in image classification: supervised and unsupervised classification. Supervised classification methods use samples of known class identity to establish decision rules. Unsupervised classification methods divide data into different spectral classes based on spectral similarity measures.

***Measurement Of Image, Plotting Of Details And Transferring Information On To The Map* Sheet**

The images in Remote Sensing are a graphical records of various objects on earth surface in two dimensions. Different points, defining the images of various objects are recorded in planimetry, having X and Y coordinates. Such coordinates can be measured by various instruments. However, from these primary measurements, other values such as length, area, volume, height, distance, etc. can also be worked out. The darkness (density) or brightness of a point is measured using densitometric devices. A large number of measuring devices including Photogrammetric instruments are available. Using these measurements, and a suitable mathematical model, the location of imaged points in space can be determined. Modern measurement and mapping systems such as Photogrammetric Stereo plotters, as well as Digital Photogrammetric Mapping Systems are available, where once the image of some object is identified, using the measuring mark or a cursor, the location of that object in space (it's coordinates) are calculated and displayed almost in real time. Global Positioning Systems (GPS) are now a days widely used for improving efficiency of field measurements (associated with Ground Control Points) in mapping.

A map is a graphical representation of data about various themes, presented with conventional symbols. The information obtained by analysis and measurement of images is therefore generalized before presenting it in a map. Some of processed form of images, such as Orthophoto, Rectified Photographs, Geocoded Imageries etc., have some geometrical characteristics of map inherited in themselves and often can be used as Map Substitute. For preparing a conventional and authentic map from Remote Sensing Image Data, steps involve geometric corrections and treatment for respective map projection (e.g. polyconic, UTM etc.) and to include ancillary information, names of town, roads, villages, rivers etc., Grid values for Northing and Easting and other information including Ground Verification.

Depending upon accuracy and speed requirements, a number of techniques and instruments are available for mapping and transfer of details from image to map. The simple techniques such as tracing the details from image to map can be done by putting a tracing paper over the photo (image). This will not correct any deviation in scale or distortion, and thus, it will be the simplest, cheapest, quick and crude method. Using Optical Transfer Instruments (such as optical pantograph, aero sketch master) or mechanical devices such as mechanical pantograph, scale of plotting can be reduced or enlarged and can be corrected to a known round off value. However, the inherent image distortions such as tilt, relief, affine, and lens distortions can not be corrected by it. Some such instruments are however provided with image manipulation devices (e.g. image stretching in stereo zoom transferscope) to make a best possible fit while transferring details from image to map. Such instruments are moderately economical in use but lack the ability to exploit the full potential of image for mapping. A large number of different types of Photogrammetric Stereoplotters are available. Such plotters work on the principle of reconstructing the image geometry in order to obtain a precise solution for determining the location of various points in space. Such instruments are expensive and comparatively slow in output, but highly accurate. Recent development have taken place in this field, as a result of which computerized systems are available for mapping. Digital Photogrammetry (also known as Soft Copy Photogrammetry) deals with new techniques in mapping, where the photographs and images are converted into digital form, and then entire process of image analysis, cartography and mapping is done in intensively computerized environment. Such systems are often associated with, or a part of a much wider Information System (usually known as Geo Information System). The information about the newly created maps as well as updating done on existing maps constitutes the data base of such information systems.

Optical Sensors Used In Remote Sensing Systems

Scanner systems working beyond the visible and near infrared range of the electromagnetic spectrum, in thermal and microwave region (RADAR) are all non-photographic systems. Some of the non-photographic data acquisition systems available for resource survey, sensitive in Visible & Near IR region are mentioned below.

Multispectral Scanner (Mss) Used In Landsat Series Satellites

Multispectral scanner (Optical Mechanical Scanner) onboard Landsat series of satellites of U.S.A. (L1, L2, L3, L4 & L5) gives line scan type imagery using an oscillating mirror to continuously scan the earth surface perpendicular to the spacecraft velocity. Six lines are scanned simultaneously in each of the four spectral bands for each mirror sweep. Spacecraft motion provides the along-track progression of the scan lines. Radiation is sensed simultaneously by an array of six detectors each of four spectral bands from 0.5 to 1.1 micrometers. The detectors’ outputs are sampled, encoded and formatted into continuous digital data stream.

Thematic Mapper (TM) Used In Landsat Series Satellites

Landsat 4 & 5 have onboard a new payload called "Thematic Mapper" with 7 spectral bands & ground resolution of 30 meters. This is in addition to the MSS payload which is identical to those carried onboard Landsat 1 & 2 and replaces RBV payload. TM is also an Optical Mechanical Scanner, similar to MSS; however, being a 2nd generation line scanning sensor, it ensures better performance characteristics in terms of (i) improved pointing accuracy and stability, (ii) high resolution, (iii) new and more number of spectral bands, (iv) 16 days repetitive coverage (v) high scanning efficiency using bi-directional scanning and (vi) increased quantization levels. For achieving the bi-directional scanning, a scanline corrector (SLC) is introduced between the telescope and focal plane. The SLC ensures parallel lines of scanning in the forward and reverse direction.

High Resolution Visible (HRV) Imager Used In SPOT Satellite

The French SPOT-1 spacecraft carries two nominally identical High Resolution Visible (HRV) imagers, which can be operated independently or in various coupled modes. In contrast to the oscillating mirror design used in the Landsat imaging system, HRV cameras use Charge Coupled Devices (CCD) array as the sensing element for the first time in space environment. Each of the two cameras can be operated in either multispectral (20 m resolution) mode or panchromatic (10 m resolution) mode. The swath covered is 60 Km; and the cameras can be tilted offset upto 27° on either side of Nadir. Thus any point within a width of 950 km., centered on the satellite track can be observed by programmed camera control. SPOT-1 has stereo coverage capability in orbit with tiltable cameras, which again provides stereo image pair almost similar to metric camera air photos, for the first time in space environment.

Linear Image Self Scanning (LISS) Camera Used In IRS-1A & 1B

Indian Remote Sensing Satellite (IRS-1A) fully designed and fabricated by the Indian Space Research Organization (ISRO) was launched on March 17th, 1988 by Russian launcher. It has four spectral bands in the range of 0.45 to 0.86 μm (0.45 to 0.53 μm to 0.59 μm, 0.62 to 0.68 μm and 0.77 to 0.86 μm) in the visible and near infrared range with two different spatial resolution of 72.5 m. and 36.25 meter from one no. of open LISS-1 and two nos. of LISS-2 cameras respectively. It provides repetitive coverage after every 22 days. Like all other LANDSAT/ SPOT missions which are designed for global coverage IRS is also in sun synchronous, polar orbit at about 900 km altitude and cover a width of 148 km. on ground. It uses linear array detectors (CCD) like SPOT.

Linear Imaging Self Scanning Camera-3 (LISS-3)

This camera is configured to provide imageries in three visible bands as well as in short-wave infrared band. The resolution and swath for visible bands are 23.5 m and 142 km, respectively. The detector is a 6000 element CCD based linear array with a pixel dimension of 10μm by 7 μm. The detector is placed at the focus of a refractive type optical system consisting of eight lens elements, which provides a focal length of 360 mm.

The processing of the analogue output video signal is similar to that of PAN. For this camera, a 7-bit digitization is used which gives an intensity variation of 128 levels.

Linear Imaging Self-Scanning Camera-4 (LISS-4)

LISS-4 camera serves the dual purpose of acquiring 70 km swath, mono images giving continuity to the PAN camera of 1C/ 1D. In its normal mode it acquires 23 km swath 3 band multispectral imagery, which can be positioned anywhere in the 70 km coverage of Mono mode. The enhanced dynamic range of 10 bits is intended to serve the worldwide requirement of radiometric ranges. The stereo capability of 1C/ 1D is retained to provide the across track stereo to the requirement of the users. The camera can be tilted 26 degrees across track.

Table 1 Characteristics of LISS-3/ LISS-4.

	LISS-3	LISS-4
Spectral Bands	B2 0.52-0.59 µm B3 0.62-0.68 µm B4 0.77-0.86 µm B5 1.55-1.70 µm	B2 0.52 - 0.59 B3 0.62 - 0.68 B4 0.77 - 0.86
Geometric resolution	23.5 m for bands 2,3,4 70.5 m for band 5	5.8 m (at nadir)
Equivalent focal length (bands 2, 3, 4/ band 5)	347.5 mm/301.2 mm	
Swath	141 km for bands 2,3,4 148 km for band 5	23.9 km MS mode 70 km PAN mode
Radiometric resolution	7 bits	10 bits
Band-to-band registration	±0.25 pixel	

Panchromatic Camera (PAN)

The PAN camera is configured to provide the imageries of the Earth in visible spectrum, in a panchromatic band (0.5-0.75 m) with a geometric resolution of greater than 10 m and a swath of 70 km. The camera uses an off-axis reflective type optics system consisting of three mirrors for providing the required focal length. A 7µm pixel sized CCD is being used as the detector element. Using three linear array charge-coupled detectors covers the total swath of 70 km and each of these detectors covers a swath of about 24 km. The central detector is offset from the other two detectors by a distance in focal plane that corresponds to 8.6 km on the ground. The other two detectors cover swath of 24 km each adjacent to the central CCD. These two detectors are aligned with an accuracy of 30 arc sec^{-1}. The overlap of the central swath with the side swaths is 600 m on the ground. Each of the detectors provides four analogue outputs, which are independently processed by video chains, converted to digital and providing a data handling system for formatting.

For a PAN data compatible with the expected signal to noise ratio, a 6-bit digitization is used which gives 64 radiometric gray levels.

The PAN payload with its capability to tilt ±26^{o}, can view (revisit) any particular scene once in 5 days, if required. Additionally this provision can be used for getting stereo pairs or imageries. The tilting capability is achieved by steering the camera as a whole by the required angle using a steering mechanism to which PAN camera plugs are fixed. Table-2 gives the characteristics of PAN camera.

Table 2 Characteristics of PAN camera.

Geometric resolution from altitude of 817 km	5.8 m
Effective focal length for optics	980 mm
Swath	70 km
Field-of-view for optics	±2.5^{o} (across track) ±0.3^{o} (along track)
Spectral band	0.5-0.75 µm

Wide Field Sensor (WiFS)

This camera operates in two bands B3: 0.62 µm to 0.68 µm (Red) and B4: 0.77 µm to 0.86 µm (NIR). Each band uses a 2048 element CCD with an element size of 13 µm by 13 µm. A wide-angle refractive optics system with 8-lens elements is used with a focal length of about 56 mm. This payload required to cover a ground swath of 770 km with a resolution of 188 m. This ground swath with the selected 817 km orbit can provide the required repetivity for the intended application.

To cover the 770 km, two separate band assemblies are used for each band. Thus the entire swath in each band is covered by two detectors. Each of the detectors covers half of the swath. The signal processing chain in similar to LISS-3 wherein the analogue video signal is converted to 7 bits and given to data handling system for formatting. Table 3 gives the characteristics of WiFS camera.

Table 3 Characteristics of WiFS.

Band 3	0.62-0.68 µm
Band 4	0.77-0.86 µm
Resolution	188.3 m
Swath	810 km
Radiometric resolution	7 bits
Band-to-band registration	±0.25 pixel

Thermal Scanners

In a thermal image, the tone of an object is a function of its surface temperature and its emissivity. Of these, parameters, the surface temperature is the dominant factor for producing tonal variations in the scene. All objects emit infrared radiation and the amount of emitted radiation is a function of surface temperature. Hot bodies appear in lighter tone in a thermal image and cooler bodies appear darker. The emitted radiation are collected by thermal scanner, which works on the principle of Optical Mechanical Scanner, and cryogenically cooled detectors are employed to sense the radiation in the wavelength of 8 to 14 micron wavelength. Temperature variations of up to one degree centigrade can be estimated from the thermal imagery.

Table 4 Thermal sensors.

	HCMM	TM
Operational period	1978-1980	1982 to present
Orbital altitude	620 Km	705 Km
Image coverage	700 by 700 Km	185 by 170 Km
Acquisition time, day	1:30 p.m.	10:30 a.m.
Acquisition time, night	2:30 a.m.	9:30 p.m.
Visible and reflected IR detectors		
Number of bands	1	6
Spectral range	0.50 - 1.1μm	0.4 - 2.35 μm
Ground resolution cell	500 by 500 m	30 by 30 m
Thermal IR detector		
Spectral range	10.5 - 12.5 μm	10.5 - 12.5μm
Ground resolution cell	600 by 600 m	120 by 120m

Microwave Sensing Radar

Microwave data can be obtained by both active and passive systems. Passive system monitor natural radiation at a particular frequency or range of frequency. Data may be presented numerically as line trace data or as imagery. Active systems (like SLAR and SAR) transmit their own energy and monitor the returned signal.

Characteristics of such radar imagery both in SAR and SLAR and their resolution depends on various parameters like frequency of the signal, look direction, slant range, dielectric constant of the objects, phase, antenna length etc. Spatial resolution in range and azimuth direction varies in different manners.

RADAR (SAR) imageries have been obtained from satellite SEASAT, ERS and space shuttle missions SIR-A, SIR-B and SIR-C using synthetic aperture radar, which has all weather capability. Such data products are useful for studies in cloud-covered region of the earth and in oceanography.

Table 5 Microwave sensors.

	Seasat SAR	SIR-C/X-SAR	ESA SAR	RADARSAT SAR	ENVISAT ASAR	JERS-1
Frequency	1.275 GHz	5.3 GHz 1.275 GHz	5.3 GHz	5.3 GHz	5.33 GHz	1.275 GHz
Wavelength	L band 23 cm	X band 3cm C band 6cm L band 23 cm	C band	C band	C Band	L Band (23cm)
Swath Width	100 Km, centered 20^o off nadir	15 to 90 Km Depend on orientation is antenna	100 Km	45-510 Km Varies	5 Km – 100 Km Varies	75 km
Ground Resolution	25 x 25 m	10 to 200m	30 m	100x100 m to 9x9m Varies	Varies	30 m

Satellite Missions

LANDSAT Series Of Satellites

NASA, with the co-operation of the U.S. Department of Interior, began a conceptual study of the feasibility of a series of Earth Resources Technology Satellites (ERTS). ERTS-1 was launched on July 23, 1972, and operated until January 6, 1978. It represented the first unmanned satellite specifically designed to acquire data about earth resources on a systematic, repetitive, medium resolution, multispectral basis. It was primarily designed as an experimental system to test that feasibility of collecting earth resources data from unmanned satellites. About 300 individual ERTS-1 experiments were conducted in 43 US states and 36 nations. Just prior to the launch of ERTS-B on January 22nd 1975, NASA officially renamed the ERTS programme as "LANDSAT" programme. All subsequent satellites in the series carried the Landsat designation. So far five Landsat satellites have been launched successfully, and Landsat-6 suffered launch failure. Table highlights the characteristics of the Landsat series satellites mission. There have been four different types of sensors included in various combinations on these missions. These are Return Beam Vidicon camera (RBV) systems, Multispectral Scanner (MSS) systems, Thematic Mapper (TM) and Enhanced Thematic Mapper (ETM).

After more than two decades of success, the LANDSAT program realized its first unsuccessful mission with the launch failure of Landsat-6 on October 5, 1993. The sensor included on-board was the Enhanced Thematic Mapper (ETM). To provide continuity with Landsat -4 and -5 the ETM incorporated the same seven spectral bands and the same spatial resolutions as the TM. The ETM's major improvement over the TM was addition of an eighth panchromatic band operating in 0.50 to 0.90µm ranges a spatial resolution of 15m. Landsat-7 includes two sensors: the Enhanced Thematic Mapper plus (ETM+) and the High Resolution Multispectral Stereo Imager (HRMSI).

Table 6 Characteristics of LANDSAT missions.

Sensor-system	Spectral resolution (µm)	Spatial resolution (m)	Scan-width (km)	Time interval Equator	Orbital altitude	Operation period
MSS	Band 4: 0,5 - 0,6	79×79	185	18 days	918 km	LANDSAT 1 23/07/1972 - 06/01/1978 LANDSAT 2 22/01/1975 - 25/02/1982 LANDSAT 3 05/03/1978 - 30/11/1982
	Band 5: 0,6 - 0,7	79×79				
	Band 6: 0,7 - 0,8	79×79				
	Band 7: 0,8 - 1,1	79×79				
MSS	As LANDSAT-3		185	16 days	710 km	LANDSAT 4 16/07/1982 - 02/1983 LANDSAT 5 01/03/1984 *LANDSAT 6 05/10/1993 Launch failure*
TM	Band 1: 0,45 - 0,52	30×30				
	Band 2: 0,52 - 0,60	30×30				
	Band 3: 0,63 - 0,69	30×30				
	Band 4: 0,76 - 0,90	30×30				
	Band 5: 1,55 - 1,75	30×30				
	Band 6: 10,40 - 12,50	120×120				
	Band 7: 2,08 - 2,35	30×30				
TM	As LANDSAT-5	30x30	185	16 days	705 Km	LANDSAT 7 15/04/1999 *Band 8 failed soon after launch*
	Band 6: 10,40 - 12,50	60×60				
	Panchromatic: 0.50 - 0.90	15×15				

MODIS And ASTER

MODIS (or Moderate resolution Imaging Spectro-radiometer) is the key instrument aboard the Terra (EOS AM-1) satellite. Terra MODIS is viewing the entire Earth's surface every 1 to 2 days, acquiring data in 36 spectral bands, or groups of wavelengths.

The MODIS instrument provides high-resolution sensitivity (12) bit in 36 spectral bands ranging in wavelength from 0.4 micrometer to 14.4 micrometer. Two bands are imaged at a nominal resolution of 250 m at nadir, with five bands at 500 meter and the remaining 29 bands at 1,000 m.

The first Earth Observing System (EOS) satellite called Terra (previously AM-1) was launched on December 18, 1999 from the Vandenberg Air Force Base in California. ASTER is one of the five state-of-the-art instrument sensor systems on-board Terra with a unique combination of wide spectral coverage and high spatial resolution in the visible near infrared through short-wave infrared to the thermal infrared regions.

Table 7 Characteristics of spectral bands of Aster.

Subsystem	Band No.	Spectral Range (µm)	Spatial Resolution

VNIR	1 2 3 4	0.52 - 0.60 0.63 - 0.69 0.78 - 0.86 0.78 - 0.86	15 mts
SWIR	5 6 7 8 9 10	1.600 - 1.700 2.145 - 2.185 2.185 - 2.225 2.235 - 2.285 2.295 - 2.365 2.360 - 2.430	30 mts
TIR	11 12 13 14 15	8.125 - 8.475 8.475 - 8.825 8.925 - 9.275 10.25 - 10.95 10.95 - 11.65	90 mts

SPOT Series Of Satellite

French Government in joint programme with Sweden and Belgium undertook the development of Systeme Pour l'Observation de la Terre (SPOT) program. Conceived and designed by the French Centre National d'Etudes Spatiales (CNES), SPOT has developed into a large-scale international programme with ground receiving stations and data distribution outlets located in more than 30 countries. It is also the first system to have pointable optics. This enables side-to-side off-nadir viewing capabilities, and it affords full scene stereoscopic imaging from two different satellite tracks permitting coverage of the same area. SPOT-1 was retired from full-time services on December 31, 1990. The SPOT-2 satellite was launched on January 21, 1990, and SPOT-3 was launched on September 25, 1993 Spot 4 was launched on 26 March 1998. SPOT-1, -2 and -3 have identical orbits and sensor systems, which are described in the Table 8.

SPOT-4 includes the additional 20m-resolution band in the mid-infrared portion of the spectrum (between 1.58 and 1.75µm). This band is intended to improve vegetation monitoring and mineral discriminating capabilities of the data. Furthermore, mixed 20m and 10m data sets will be co-registered on-board instead of during ground processing. This will be accomplished by replacing the panchromatic band of SPOT-1, -2 and -3 (0.49 to 0.73 µm) with red band from these systems (0.61 to 0.68 µm). This band will be used to produce both 10m black and white images and 20m multispectral data. Another change in SPOT-4 is the addition of a separate wide-field-of-view, sensor called the Vegetation Monitoring Instrument (VMI).

SPOT-5 is the latest in France's series of Earth observing satellites, all of which were sent into orbit by Arian space. Since the first SPOT satellite was launched in 1986, the SPOT system has sought to provide continuity of service and constantly improved quality of products for users. Spot 5 is the fifth satellite in the SPOT series, placed into orbit by an Ariane5 launcher in May 2002.

Table 8 Characteristics of SPOT series of satellites.

Satellite Name	Launch	Sensors	Types	No. of Channels	Spectral Range (μm)	Resolution (meters)	Swath Width (km)	Revisit Time
SPOT -5	May 2002	VMI	Multispectral	4	0.43-0.47 (blue) 0.61-0.68(red) 0.78-0.89(NIR) 1.58-1.75(SWIR)	1000	600 x 120	1 day
		HRS	Multispectral	4	0.5-0.59 (green) 0.61-0.68 (red) 0.79-0.89 (NIR) 1.58-1.75 (SWIR)	10 10 10 20	60	26 days
		HRG	Pan	1	0.61-0.68	5 m, combined to generate a 2.5-metre product.	60	
			Pan	1	0.61-0.68	10 m (resampled at every 5m along track)	60	
SPOT-4	March 24, 1998	VMI	Multispectral	4	Same as SPOT 5	I000	600 x 120	26 days
		HRV	Multispectral	4	Same as SPOT 5	20	60	
			Pan	1	0.61-0.68	10	60	
SPOT-2 & 3	1990 & March 1998	HRV	Multispectral	3	0.5-0.59 0.61-0.68 0.79-0.89	20	60	26 days
			Pan	1	0.51-0.73	10	60	
SPOT-1	1986	HRV	Multispectral	3	Same as Spot 2	20	-do-	26 days
			Pan	1	Same as Spot 2	10	-do-	

IRS Satellite Series

The Indian Space programme has the goal of harnessing space technology for application in the areas of communications, broadcasting, meteorology and remote sensing. The important milestones crossed so far are Bhaskara-1 and 2 (1979) the experimental satellites, which carried TV Cameras and Microwave Radiometers. The Indian Remote Sensing Satellite was the next logical step towards the National operational satellites that directly generates resources information in a variety of application areas such as forestry, geology, agriculture and hydrology. IRS -1A/1B, carried Linear Self Scanning sensors LISS-I & LISS-II. IRS-P2 launched in October 1994 on PSLV-D2 (an indigenous launch vehicle). IRS-1C, launched on December 28, 1995, which carried improved sensors like LISS-III, WiFS, PAN Camera, etc. Details of IRS series platforms are given in the following section. IRS-P3 was launched into the sun synchronous orbit by another indigenous launch vehicle PSLV - D3 on 21.3.1996 from Indian launching station Sriharikota (SHAR). IRS-1D was launched on 29 September 1997 and IRS-P4 was launched on 26 May 1999 onboard PSLV from Shriharikota.

IRS-P4 (Oceansat-1)

IRS-P4 carries an Ocean Colour Monitor (OCM) and a Multi-frequency Scanning Microwave Radiometer (MSMR), launched on May 26 1999. OCM has 8 narrow spectral bands operating in visible and near-infrared bands (402-885 nm) with a spatial resolution of 350 m and swath of 1500 kms. IRS P4 OCM thus provides highest spatial resolution compared to any other contemporary satellites in the international arena during this time frame. The MSMR with its all weather capability is configured to have measurements at 4 frequencies (6.6, 10.6, 18 & 26 GHZ) with an overall swath of 1500 km. The spatial resolution is 120, 80, 40 and 40 kms for the frequency bands of 6.6, 10.6, 18 and 26 GHz. MSMR will also be in a way a unique sensor as no other passive microwave radiometer is operational in the civilian domain today and will be useful for study of both physical oceanographic and meteorological parameters.

Table 9 Details of IRS Series of satellites.

Satellite Name	Launch	Sensors	Types	No. of Bands	Spectral Range (microns)	Resolution (meters)	Swath Width (km)	Revisit Time
Cartosat - 1	May 5, 2005	Pan	Mono and Stereo	8	0.5 - 0.85	2.5 m	30 km	5 days
IRS-P6 (Resource -sat)	October 17, 2003	AWiFS	Multispectral	3	0.52-0.59 (green)	56 (nadir) 70 (at field edge)	370 each head 740 (combined)	5 day
					0.62-0.68 (red)			
					0.77-0.86 (NIR)			
				1	1.55-1.70 (SWIR)			
		LISS-III	Multispectral	3	0.52-0.59 (green)	23	141	24-25 days
					0.62-0.68 (red)			
					0.77-0.86 (NIR)			
				1	1.55-1.70 (SWIR)			
		LISS-IV	Multispectral	3	0.52-0.59 (green)	5.8	23 MX mode 70 PAN mode	
					0.62-0.68 (red)			
					0.77-0.86 (NIR)			
IRS-P4 (Oceansat)	May 26, 1999	OCM	Multispectral	8	0.4 - 0.885	360 m	1420 km	2 days
		MSMR	RADAR	4	6.6,10.65, 18, 21 GHz	120, 80, 40 and 40 kms	1360 km	
IRS-1D	September 29, 1997	WiFS	Multispectral	2	0.62-0.68 (red)	189	774	5 day
					0.77-0.86 (NIR)			
		LISS-III	Multispectral	3	0.52-0.59 (green)	23	142	24-25 days
					0.62-0.68 (red)			
					0.77-0.86 (NIR)			
				1	1.55-1.70 (SWIR)	70	148	
		PAN	PAN	1	0.50-0.75	6	70	
IRS-1C	December 28, 1995	WiFS	Multispectral	2	0.62-0.68 (red)	189	810	5 day
					0.77-0.86 (NIR)			
		LISS-III	Multispectral	3	0.52-0.59 (green)	23.6	142	24-25 days
					0.62-0.68 (red)			
					0.77-0.86 (NIR)			
				1	1.55-1.70 (SWIR)	70.8	148	
		PAN	PAN	1	0.50-0.75	5.8	70	
IRS-1B	1991	LISS-I	Multispectral	4	0.45-0.52	72.5	148	22 days
					0.52-0.59			
					0.62-0.68			
					0.77-0.86 (NIR)			
		LISS-II	Multispectral	4	Same as LISS I	36.25	74	
IRS-1A	1988	LISS-I	Multispectral	4	Same as IRS- 1B	72.5	148	22 days
		LISS-II	Multispectral	4		36.25	74	

Table10(a) Orbital characteristics of IRS series of satellites (IRS-1A/1B, P2).

Features	IRS-1A/1B	IRS-P2
Altitude	904 km	817 km

Orbital period Temporal resolution Equatorial crossing time (local sun time)	103.2 min 22 days 10.00 AM	101.35 min 24 days 10.00 AM

Table 10(b) Orbital characteristics of IRS series of satellites.

Features	IRS-1C	IRS-1D	IRS-P6
Orbit type	Polar Sun sync.	Polar Sun sync.	Polar Sun sync.
Altitude	817 km	780 km (mean)	817 km
Inclination	98.69°	98.53°	98.69°
Adjacent paths distance	117.5 km	111.94 km	117.5 km
Repetivity for LISS-3	24 days	25 days	24 days
Repetivity for WIFS	5 days	3 days *	LISS-4 Specifications
Revisit for PAN	5 days	3 days *	*IGFOV- 5.8 m at nadir*
Off-nadir coverage	398 km	407 km	*Swath - 23.9 km MS mode*
± 26^{o} for PAN			*Quantization- 10 bits*
Stereo viewing capability	5 days	3 days *	*B2 0.52 - 0.59*
		*(For IRS-1C/ 1D both)	*B3 0.62 - 0.68*
			B4 0.77 - 0.86

RESOURCESAT-1

RESOURCESAT-1 was launched by ISRO's Polar Satellite Launch Vehicle, PSLV-C5, from Satish Dhawan Space Centre-SHAR on October 17, 2003. RESOURCESAT-1 carries three cameras on board:

(i) A multi-spectral high spatial resolution camera, namely, Linear Imaging Self Scanner-4 (LISS-4) providing a spatial resolution of 5.8 m and a swath of 23 km. It operates in the Visible and Near Infra Red spectral bands. LISS-4 can also be operated in monochromatic (black and white) mode providing a spatial resolution of 5.8 m and a swath of 70 km. Besides, the camera can be steered across track to take stereoscopic imagery.

(ii) A multi-spectral Linear Imaging Self Scanner-3 (LISS-3), which has a spatial resolution of 23 m and a swath of 141 km. It operates in the Visible, Near Infra Red and Short Wave Infra Red spectral bands.

(iii) A multi-spectral Advanced Wide Field Sensor (AWiFS) with a spatial resolution of 56 m providing a swath of 740 km. The camera operates in the Visible, Near Infra Red and Short Wave Infra Red spectral bands. AWiFS is a unique camera having the capability to take the imagery of the world repeatedly every 5 days with a very high radiometric resolution. With the unique combination of cameras providing imageries with high spatial, spectral, temporal and radiometric resolutions, RESOURCESAT-1 is expected to enhance the remote sensing applications, especially, in the fields of agriculture, land and water resources management, and, disaster management.

IRS-P5 (CARTOSAT-1)

This mission has a PAN sensor with 2.5 m resolution with fore-aft stereo capability to cater for applications in cartography, terrain modeling, cadastral mapping etc. CARTOSAT-1 is launched on May 5th, 2005 by PSLV.

Table 11 Characteristics of Cartosat-1 satellite.

Features	Cartosat-1 Specifications
Orbit	618 km high, circular Polar Sun synchronous
Orbit inclination	98.87 deg
Orbit Period	97 min
Number of orbits per day	14
Local time of equator crossing	10.30 AM
Repetivity	126 days
Revisit	5 days
Lift-off mass	1560 kg
Payloads	Two PAN cameras (Pan fore mounted with a tilt of +26 deg and Pan aft mounted with a tilt of -5 deg from the yaw axis to generate stereoscopic imagery)
IFOV	< 2.5 m
Swath	30 km
Spectral band	0.50 – 0.85 µm
Data rate	105 Mbps for each camera
Solid state recorder	120 GB capacity for image data storage

CLIMATSAT/ OCEANSAT-2

In order to meet the information requirements to study the Planet Earth as an integrated system, satellite missions are planned which would enable global observations of climate, ocean and the atmosphere, particularly covering the tropical region, where sufficient datasets are not available. The instruments like radiometers, sounders, spectrometers etc. for studying the land, ocean and atmospheric interactions are being planned for these missions.

Future Indian Satellite Missions

CLIMATSAT/OCEANSAT-2

In order to meet the information requirements to study the Planet Earth as an integrated system, satellite missions are planned which would enable global observations of climate, ocean and the atmosphere, particularly covering the tropical region, where sufficient datasets are not available. The instruments like radiometers, sounders, spectrometers etc. for studying the land, ocean and atmospheric interactions are being planned for these missions.

Latest International High-Resolution Satellite Missions (IKONOS)

The IKONOS-2 satellite was launched in September 1999 and has been delivering commercial data since early 2000. IKONOS is the first of the next generation of high spatial resolution satellites. IKONOS data records 4 channels of multispectral data at 4-meter resolution and one panchromatic channel with 1-meter resolution. This means that IKONOS is first commercial satellite to deliver near photographic quality imagery of anywhere in the world from space.

Radiometric Resolution: Data is collected as 11 bits per pixel (2048 gray tones). Timings of collecting / receiving IKONOS data and satellite orbit characteristics vary considerably depending on accuracy of product, extent and area.

Table 12 Characteristics of IKONOS-2 satellite.

Launch	Sensors	Types	No. of Bands	Spectral Range (µm)	Resolution (m)	Revisit Time
September 24, 1999	IKONOS	Multi-spectral	4	0.45-0.52 (blue) 0.52-0.60 (green) 0.63-0.69 (red) 0.76-0.90 (NIR)	4	11 days
		Pan	1	0.45-0.90	1 m	

OrbView-3

ORBIMAGE's OrbView satellite is one of the world's first high-resolution optical imaging satellites. It was launched on June 26th 2003. It collects 1m Panchromatic and 4m multispectral imagery with a swath width of 8 km. The satellite revisits each location on earth in less than 3 days with an ability to turn from side-to-side upto 45 degrees. Its imagery has many applications including mapping, environmental and agricultural monitoring, land use and land classification, natural disaster assessment, national security and forestry mapping etc.

Table 13 Characteristics of OrbView-3 satellite.

Satellite Name	Orbital Altitude (km)	Launch	Sensors Types	Spectral Range (µm)	Resolution (meters)	Swath Width (km)	Revisit Time
OrbView-3	470	26 June 2003	Multispectral	0.45-0.52 (blue) 0.52-0.60 (green) 0.625-0.695 (red) 0.76-0.90 (NIR)	4	8	Less than 3 days
			Pan	0.49-0.90	1		

Suggested Readings

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