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The Indian remote sensing satellite: a programme overview

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Abstract. The Indian remote sensing satellite (IRS) programme, is a major step forward in the overall programme for using space technology for defined applications in India. The principal elements of this programme are (i) to design, develop and deploy a three-axis stabilized polar sun-synchronous satellite carrying state-of-the-art payloads using charge coupled devices for acquiring images of the earth, (ii) to establish and routinely operate ground-based systems for spacecraft control, data reception and recording, processing, generation of data products, analysis and archival, and (iii) to use IRS data either alone or in conjunction with supplementary and complementary data for applications in selected resources surveys. Various considerations that have gone into the definition of different subsystems of each of the above are discussed in this paper. Different elements of the IRS utilization programme and their role in the evolution of a national natural resources management system are also outlined.

Keywords. Indian remote sensing satellite; remote sensing; Indian space programme; mission parameters; payload parameters, space segment; ground segment.

1. Introduction

Timely and accurate information on various natural resources, both renewable and non-renewable, is very important for the planned development of any country. For a country of India's size and population, the necessity of generating continuous and updated information on terrestrial resources and environment needs hardly any emphasis in this context. Such an information, among other things, should include aspects pertaining to meteorological, geological, geographical and ecological conditions. In this connection, space-based earth observation systems offer unique possibilities in their ability for synoptic and systematic acquisition of the related data and making available the same, with very short turn-around times to resource managers and planners.

Recognizing the above considerations, in the long term planning of the Indian space programme, realization of operational capabilities in remote sensing using space platforms for the monitoring of earth resources and environment ranks high on the priority. Evolution of the related efforts over the last one decade included conduct of aerial flights, development of a variety of remote sensors, setting up of ground-based data processing and interpretation hardwares and carrying out specific end-to-end application experiments using aerial and satellite imagery in close co-ordination with a number of user agencies.

One of the major landmarks in these efforts is the planning and implementation of *Bhaskara* I and II experimental satellite programmes in the time frame of 1976–1982. The *Bhaskara* programmes provided valuable experience and insight into a number of aspects such as sensor system definition and development, conceptualization and implementation of a space platform, ground-based data reception and processing, data interpretation and utilization as well as issues relating to the integration of the remotely-sensed data with the conventional data systems for resource management.

With this background, the Indian Space Research Organisation (ISRO) has taken the next logical step of going in for a national semi-operational/operational satellite-based remote sensing system in the eighties. Such a system besides consolidating, expanding and refining the efforts of seventies will make direct contributions to the generation of resource information in a number of areas such as agriculture, forestry, geology and hydrology and thus will serve to supplement, aid and strengthen the existing methods towards the realization of an optimally efficient resources management system for the country. The Indian remote sensing satellite, the primary theme of this paper represents the first step in this direction.

2. Scope of the mission

IRS mission envisages the planning and implementation of a satellite-based remote sensing system for earth resources survey. The principal components of the IRS system are (a) a three-axis stabilized polar sun synchronous satellite with suitable multispectral sensors, (b) ground-based data reception, recording and processing systems for the multispectral data, (c) ground systems for the in-orbit satellite control including the tracking network with the associated supporting softwares and (d) hardware/software elements for the generation of a variety of user oriented data products, data analysis and archival. Further, on the utilization side, IRS envisages timely dissemination of the requisite type and quantum of data products to the potential users and setting up of such of the mechanisms that will enable the users to integrate the resource information so derived as a part of their broader needs. Accordingly, the primary objectives of IRS mission will be

—to design, develop and deploy a three-axis stabilised polar sun-synchronous satellite carrying near state-of-art multiple solid state push-broom cameras operating in visible and near IR bands for acquiring imagery for earth resources applications on an operational basis;

—to establish and routinely operate ground-based systems for spacecraft control, data reception and recording, processing, generation of data products, analysis and archival.

—to use the data from IRS in conjunction with supplementary and complementary information from other sources for survey and management of resources in important areas such as agriculture, geology and hydrology in association with the user agencies, that will additionally enable characterisation of a future operational system for the country at the optimal level.

3. Choice of key mission parameters

The mission objectives set forth earlier translate into a set of mission parameters. The three important considerations in this context are: (i) applications envisaged under the mission, (ii) technological capabilities and constraints and (iii) desirability to have compatibility with contemporaneous remote sensing satellites. The full realisation of the applications requires that the specifications laid down for the quality and quantity of ultimate data products to be generated in terms of the spatial, spectral, radiometric and temporal resolutions of the imagery as well as the necessity of disseminating various levels of such data products with different turn around times to the users be met. The mission elements that come into play towards realising this include the choice of payload configuration, spacecraft orbit and attitude characteristics as well as the overall spacecraft platform, ground systems and data product performance criteria.

The choice of different mission parameters is interlinked with each other and trade-off analysis had to be carried out to arrive at the optimum system. Although there are many parameters related to the spacecraft, payloads, ground segment which need to be defined, discussion here is restricted to the payload characteristics, orbit selection for the satellite and its orbit and attitude stability.

3.1 *Payload parameters*

The important payload parameters of relevance to the present discussion include the spatial resolution, spectral domain and bandwidth, radiometric sensitivity as well as repetivity.

3.1a *Spatial resolution*: The spatial resolution needs for some of the broad agricultural applications in the country have been in the range of 40–70 m. One of the important applications identified is the agricultural remote sensing. This requires identification of crops as a first step; in other words, identifying contiguous areas under a single crop. Under Indian conditions this would require effective spatial resolution at least of the order of 30–40 m. Applications like the regional geological mapping, groundwater exploration, flood mapping, drought monitoring, etc. would be feasible. Other possibilities include water quality monitoring in surface water bodies of large and medium extents. Broad urban land use studies would also be possible with resolutions of the order of 30–40 m. Crop stress detection may not be possible unless its extent is over as large areas as 5 hectares.

Keeping these considerations in view, payloads with two different spatial resolutions, *viz*, 73 and 37 m, have been chosen for the IRS-1 mission. Imagery with resolution of 73 m (low resolution) besides meeting the application objectives of IRS, enable continuity of data services to the users, accustomed to LANDSAT class of imagery. Spatial resolution of about 37 m is an important improvement over LANDSAT 1, 2 and 3.

3.1b *Spectral bands and their widths*: Important parameters to be considered under this head are—number of spectral channels, centre wavelengths of the channels and bandwidths of each of the channels. Choice of each of these is specific to the application. A set suitable for an application may not be necessarily optimum for some other application. The approach to such a problem demands that the applications are given priority. As far as the applications under IRS-1 programmes are concerned, agricultural applications are considered of first priority. Vegetation mapping is an important element of this application. Hence, spectral bands chosen, have to be optimum from this application point of view.

The general spectral response of crop canopy in the visible and near infrared regions is characterized by strong absorption in the 0·35 to 0·5 and 0·6 to 0·7 μm region; higher reflectance in the green region with a maximum around 0·54 μm, a steep increase in the reflectance in 0·70–0·74 μm region and high reflectance in 0·74–1·3 μm region. The choice of spectral bands for vegetation mapping is based on these spectral characteristics, apart from the other considerations of signal-to-noise ratio, etc.

As part of the joint experiments programme, spectral signatures of various land cover types under different agroclimatic regions in different bands had been collected. In addition, ground-based signature measurements over certain crops during their entire growth cycle have also been carried out. These data have been analysed to find optimum spectral bands using different techniques by Tamilarasan *et al* (1982) and Kamat *et al* (1983). Based on these and design considerations of the payload and various application needs, a final set of spectral bands have been identified. Table 1 gives these bands for the IRS camera system. Figure 1 shows a few typical spectra of some known earth surface features together with the chosen spectral bands of IRS-1.

Physical basis for the selection of each of these bands is given in the following sections:

(i) *Band*-1: 0·45–0·52 μm

The spectral region 0·45–0·50 is characterized by absorption due to chlorophyll and carotenoid concentrations. However, from the signal-to-noise ratio considerations, one requires a minimum of 0·06 μm/bandwidth. Extending the region on the lower side beyond 0·45 of the spectral region is not advisable since the atmospheric scattering effects due to Rayleigh scattering become more pronounced at the lower wavelengths. One cannot increase the spectral region beyond 0·52 μm also, since in that case, the higher reflectance portion of vegetation starts influencing. Hence, 0·45–0·52 μm seems optimum. This region is also important from coastal environment studies, since the penetration of light into the water column is higher at shorter wavelengths. This would enable studies related to sedimentation and in special cases, may even aid bathymetry.

(ii) *Band*-2: 0·52–0·59 *μm* :

This spectral region is characterised by higher reflectance of vegetation compared to the blue and red regions. This band is of advantage for green vegetation applications, although this region is not highly correlated with green vegetation in a mixed live/dead canopy situation. However, in conjunction with measurements in the red region, this band is useful. Extending this spectral band beyond 0·59 is not advisable since it reduces the regression significance. This band is on the long wavelength side of the broad attenuation minimum of water, thus giving access to turbidity assessment and

Table 1. Spectral bands chosen for the IRS-1 cameras

Band	Spectral range	Remarks
1	0·45–0·52	Coastal environment studies, chlorophyll absorption region
2	0·52–0·59	Green vegetation, useful for discrimination of rocks and soil for their iron content.
3	0·62–0·68	Strong correlation with chlorophyll absorption in vegetation, discrimination of soil and geological boundaries.
4	0·77–0·86	Sensitive to green biomass, opaque to water resulting in high contrast with vegetation

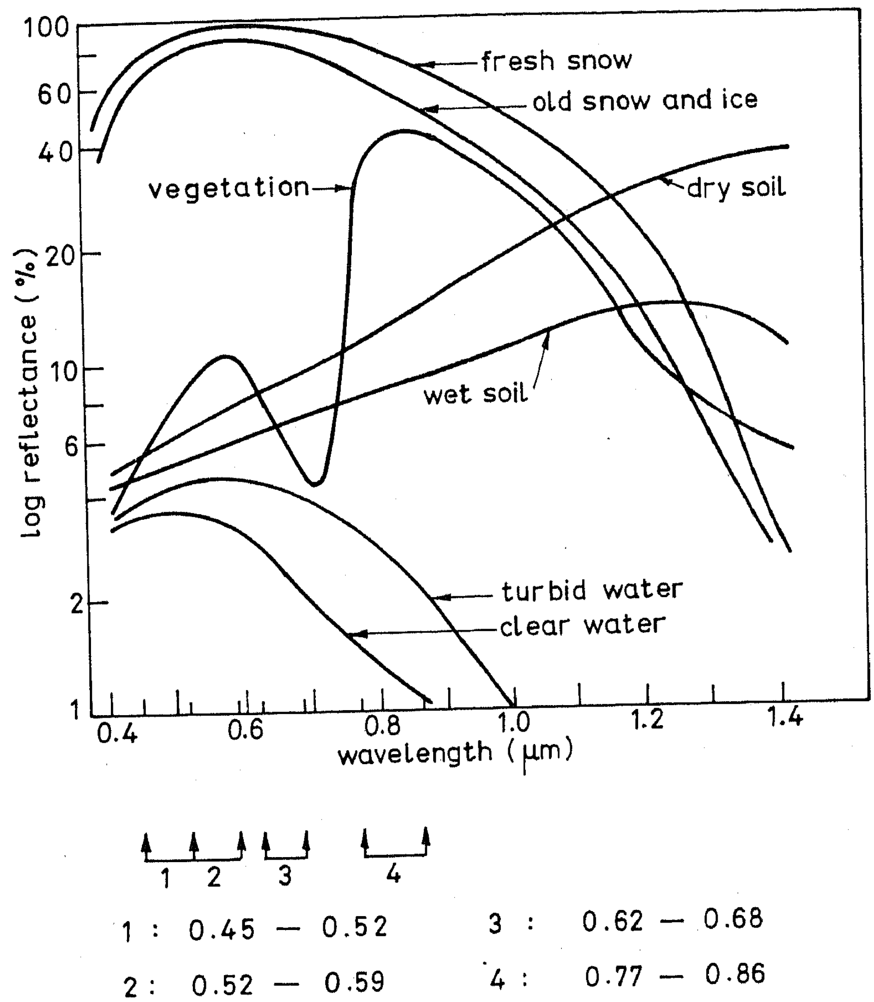

Figure 1. Spectral bands in micrometers–IRS-1

bathymetric evaluation in the first 10–20 m depth in clear water. This region is also known to be useful for discrimination of rocks and soils on the basis of their iron content.

(iii) *Band*-3: 0·62–0·68 μm
This region is characterised by strong chlorophyll absorption. Strong correlation exists between spectral reflectance in this region and the chlorophyll content. Atmospheric transmittance under good visibility conditions can be as high as 90% except around 0·69 μm, which has been avoided by limiting the spectral band to 0·68 μm. Inclusion of 0·60–0·62 μm region decreases the regression significance. It has also been shown that the geology of the areas can be inferred from the images of this band on the basis of vegetational mapping. In addition, sedimentation studies near the coast are also possible.

(iv) *Band*-4: 0·77–0·86 μm
The spectral region of 0·70–0·74 μm corresponds to the steep increase of the transition zone from low reflectance in the 0·66 μm region to the high flat reflectance pattern in the 0·74–1·3 μm region in the case of vegetation. This region (0·70–0·74 μm) is noisy,

although there has been some studies suggesting that this 'shoulder' portion of the crop spectrum is very useful in discriminating diseased plants from the normal ones. There is an absorption band due to water vapour at 0·76 μm which needs to be avoided. The region beyond 0·86 μm is not considered because of the payload design considerations like the spectral response of charge coupled devices and the integration time. The atmospheric transmittance is about 95 % for a clear atmosphere model in this region and hence 0·77–0·86 μm has been considered to be an optimum band. Quite a few studies, carried out by Singh *et al* (1982) and Tucker (1979), have shown that spectral parameters in this region are highly correlated to biometric parameters and in conjunction with band-3 this is found extremely useful. Water is almost opaque in this region providing very high contrast with vegetation.

Whereas spectral region beyond 0·86 μm has not been employed in IRS-1 owing to the limitation of the detector devices used in the camera, it will be desirable to examine the potentialities of near-IR and the real-IR for the intended applications. It is known that spectral bands in the 1·55–1·75 μm and 2·1–2·3 μm are particularly useful for moisture-stress studies in plants since they can be used to estimate plant-water content. These bands are also found useful in rock discrimination. One of the serious problems in snow mapping applications is the difficulty to distinguish snow from cloud cover with images upto 1·1 μm band. The spectral band 1·55–1·75 μm provides such a distinction since clouds absorb in this region whereas snow reflects. The usefulness of thermal infrared region is well known. Although inclusion of these spectral bands would have enhanced the application potential of IRS-1, they can be termed as technological constraints at this stage and would be considered for the follow-up missions of IRS as elaborated later.

3.1c *Radiometric resolution*: Radiometric resolution is basically the ability of the sensor to distinguish two objects radiometrically. In satellite sensors, this corresponds to the number of quantisation levels. For example, the LANDSAT multispectral scanner (MSS) has six-bit radiometric accuracy or in other words, quantizes input radiance into 64 levels. Radiometric resolution required for vegetation monitoring, in particular, for some of the thematic mapper (TM) bands of LANDSAT-4 has been analysed by Tucker (1980). Analysis has shown that quantization levels had a decided effect upon the ability to resolve spectral radiances which were highly related to plant canopy vegetational status. Two of the thematic mapper bands (3 and 4) showed a per channel improvements of 2–3 % for 256 levels over 64 levels. No improvements were found for 512 over 256 levels. The study clearly showed that either 128 or 256 quantization levels appear optimum for orbital monitoring of terrestrial vegetation for TM 3 and TM 4 bands or similar sensor bands.

Bands 3 and 4 of IRS-1 are very close to those of thematic mapper-3 and 4 bands. Seven-bit radiometric resolution planned to be provided by IRS-1 seems adequate in this context.

3.1d *Repetition cycle*: The repetition cycle of 22 days for IRS-1 based on the trade-off between orbit choice considerations and payload swath represents a compromise between the needs of dynamic resource applications, such as agriculture and hydrology, and those relating to not-so dynamic applications as in geology, land use and groundwater exploration. In a situation like crop production forecasting, the repetition cycle capabilities of IRS-1 may not fulfil the total requirements of data input. For example, wheat has approximately about 110–120 days growth cycle. Although the actual period may be less or more depending upon the agro-climatic region of the country, condition of the crops, its signatures, etc., need to be known during each of its growth stages. There are roughly about 6–7 growth stages, each approximately of 12–15 days duration. So, in an ideal situation, one would have to have data at these intervals necessitating the repetitivity to be of the order of 12–14 days.

Figure 2 summarises various considerations that have gone into the choice of sensor parameters.

3.2 *Orbit selection*

Commensurate with the constant illumination needs for earth resource observations, the orbit will be sun-synchronous (Brooks 1977). Regarding the choice of altitude, three classes of orbits have been considered around 700, 800 and 900 km. Considerations of better geographical coverage from a single ground station, low drag effects, less frequent orbit correction requirements with the attendant savings in the on-board fuel and possibility of orbit determination with better accuracies in view of reduced atmospheric modelling errors, lead to the choice of orbits with altitudes of 800 km or above.

It is to be emphasised that for an operational satellite with close tolerance requirements on orbit parameters (orbital period to be maintained within 1% to check the cross track imagery drift between successive cycles within ± 14 km), it will be desirable to restrict the number of orbit adjustment manoeuvres to the minimum during the mission period.

An orbit of 904 km altitude appears optimum for the mission considering the additional needs such as percentage overlap between contiguous strips of imagery, recurrence, swath and repetitivity for the payload observations. Further, from this altitude, the low resolution camera will provide a minimum image overlap of 10% between passes on successive days and will have repetitivity of coverage for a particular scene of 22 days.

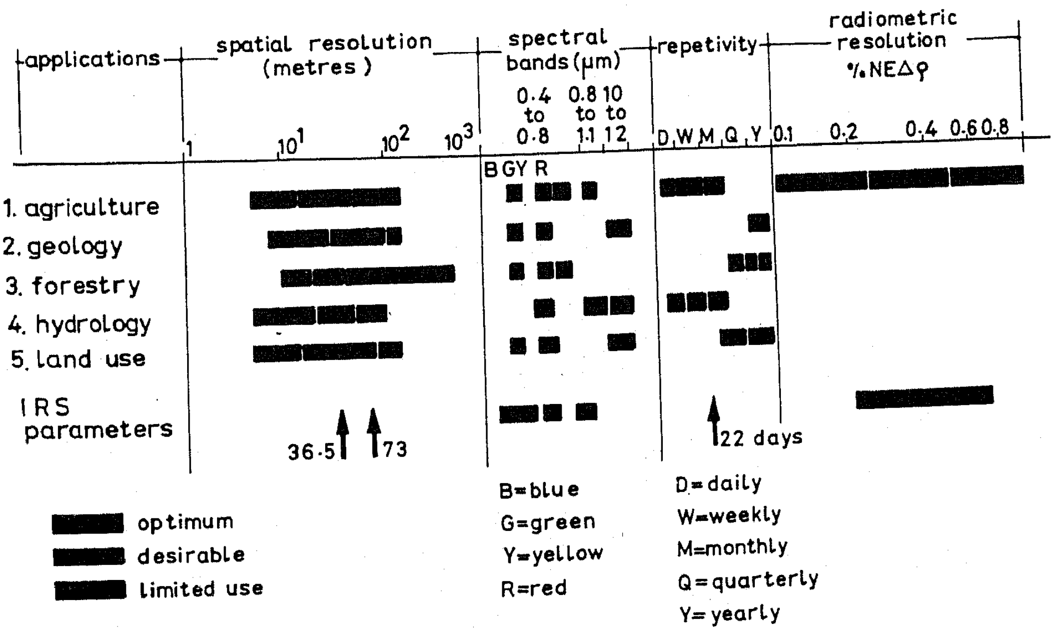

Figure 2. Selection of IRS sensor parameters

Local time for the satellite passage over India has been fixed around 10 AM as a compromise between the requirements for agriculture and geology applications. Geological applications demand low sun zenith angles since at these angles relief can be seen better because of shadow. On the other hand, agricultural applications require that the images are acquired around noon. Marine-related applications demand that sun glitter be avoided. Although bidirectional reflectance of crops is a function of sun zenith angle, it shows a flat behaviour over a certain range of zenith angles (30–50°). The local time corresponding to this may be optimum for satellite pass. Another important criteria is to see whether a certain range of local time is preferable because of statistically less significant cloud cover over the country during that time. On the basis of all these considerations, the equatorial crossing time is fixed to be around 10 AM.

Figure 3 gives the dependence of payload swath, orbit drag effects and fuel for orbit correction for a range of orbit altitudes considered for IRS. Disadvantages of a higher orbit will be the consequent reduction in the spatial resolution for same instantaneous field of view (IFOV) of the sensor system. The number of orbit adjust manoeuvres is expected to be about three per year. Table 2 gives the parameters of the chosen orbit and figure 4 illustrates the corresponding ground coverage characteristics.

3.3 *Platform and its stability*

Keeping in view the payload configuration necessary for the realisation of the applications, the spacecraft has to be three-axis body stabilised within certain limits of pointing accuracy in view of the stringent requirements of geometric fidelity in the end data products. Pixel-by-pixel identification is necessary, particularly in applications like

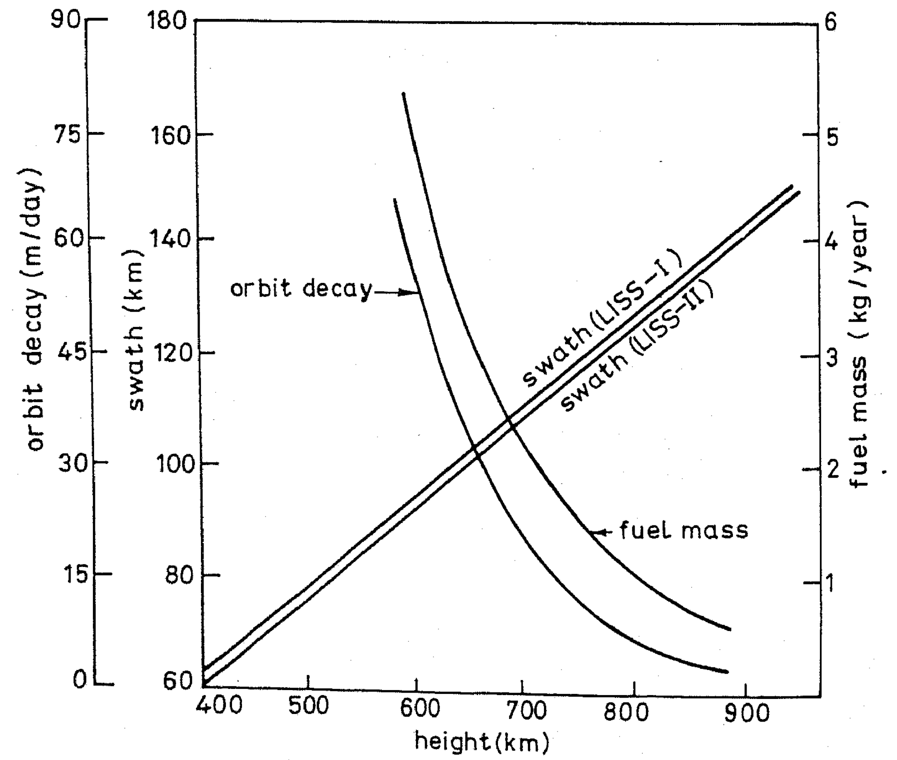

Figure 3. Orbit choice

Table 2. Summary characteristics of the IRS-1 orbit

	Parameters
Repetition cycle	22 days (307 orbits)
Orbit height (km)	904·1
Inclination (deg)	99·028
Period (min)	103·19
Orbit decay (m/day)	6
Orbit correction cycle (days)	75
Swath (km)	
Low resolution camera	148
Medium resolution camera	2 × 74
Image overlap at the equator	9·4%

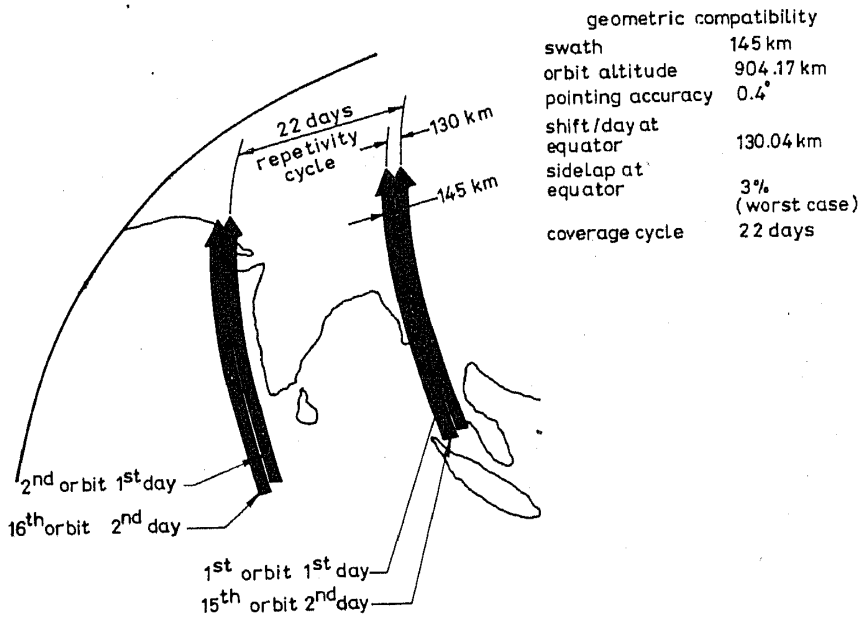

Figure 4. Orbital coverage characteristics

crop identification and acreage estimation. Such a process would require registration of multitemporal and multiband images within ±1 pixel accuracy. This puts stringent requirements on the pointing accuracy of the platform.

The attitude control system should be capable of meeting the necessary criteria in relation to pointing accuracy, drift rates and jitter. The drift rate and the pointing accuracy determine the pixel registration capability, whereas the jitter, also known as short term motion, affects the resolution characteristics. The loss of resolution because of the uncertainty in pixel position becomes significant when the jitter magnitude is about one tenth of a pixel size. The overall attitude control specifications are:

Pointing accuracy	pitch 0·4°, roll 0·4°, yaw 0·5°,
Drift	3×10^{-4} deg/s,
Jitter	3×10^{-4} deg

The attitude will be measured, atleast a factor of five better than the required pointing accuracies. The effects of attitude errors on the imagery are illustrated in figure 5.

4. Space segment

The space segment primarily consists of the payload with its data handling system and the satellite platform comprising the mainframe subsystems.

4.1 *Payload and Data handling system*

Unlike the conventional multispectral scanners, the design of IRS cameras is based on the concept of 'pushbroom' scanning, using linear imaging self-scanned sensors (LISS) (Thomson 1979). In this mode of observation, each line of the image is electronically scanned by a linear array of detectors, located in the focal plane of the system and successive lines of the image are produced as a result of the satellite's movement. Charge-coupled devices (CCDs) are used as the detectors in IRS. Such an approach has the advantages of maximizing the exposure time for each ground point and ensuring excellent photogrammetric quality along the line scan axis. The principle of pushbroom scanning is illustrated in figure 6. Each detector array provides data in a single spectral band and additional spectral bands are covered by multiple arrays with appropriate spectral separation systems.

As mentioned earlier, IRS has two types of payloads, one with low spatial resolution (73 m) henceforth designated as LISS-I and two with medium resolution (37 m) designated as LISS-II. LISS-I has a swath of 148 km whereas the same width is realised by the combined swath of the two LISS-II cameras.

Refractive type of collecting optics with spectral selection by appropriate filters are used separately for each of the four spectral bands of both LISS-I and II. Suitable logic

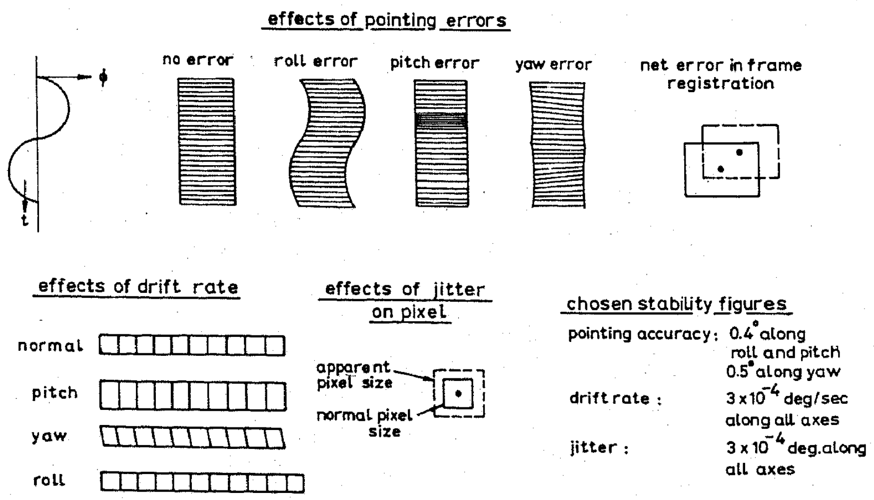

Figure 5. Effects of platform stability

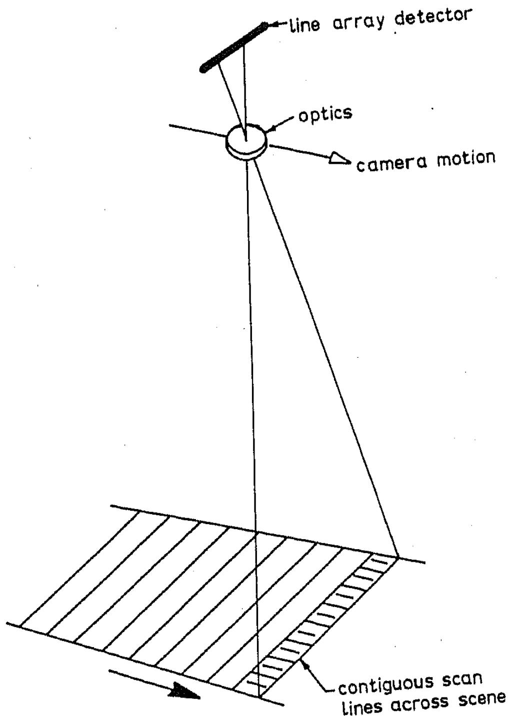

Figure 6. Illustration of the pushbroom scan technique

and signal processing, detector electronics and power supplies complete the payload system.

Brief specifications of the camera are given in table 3.

The data from LISS-I is converted into a pulse code modulation (PCM) data stream at 5·4 Mbs and transmitted through a biphase shift keying (BPSK) system in S-band at 2·2 GHz. Similarly, the data from each of the two LISS-II cameras at 10·4 Mbs are fed into I and Q channels of a quadri-phase shift keying (QPSK) modulator and transmitted in X-band at a frequency of 8·3 GHz. Both the data handling systems comprise a baseband section containing an oscillator, timing and control circuits, a formatter,

Table 3. Specifications of IRS-1 payloads

Item	Specifications	
	LISS-I	LISS-II
Focal length (mm)	162	324
FOV	9·4°	4·7° + 4·7°
IFOV (microrad)	80	40
No. of elements of CCD	2048	2048
Ground resolution (m)	73	36·5
Spectral range (μm)	0·45–0·86	0·45–0·86
No. of spectral bands	4	4
Swath (km)	148	74 × 2
Radiometric resolution	128	128
Data rate (mbps)	5·2	2 × 10·4

randomizer followed by a modulation interface for the data from the camera. The RF system contains local oscillator, modulator, power amplifier and antenna. The use of QPSK modulation scheme allows about 50% reduction in the required bandwidth compared to BPSK, while yielding similar bit error rate (BER) for the same SNR.

4.2 *Spacecraft mainframe*

The spacecraft platform essentially consists of structure, thermal control system, power system, telemetry, tracking and command system (TTC) as well as attitude and orbit control system (AOCS). The platform is configured to provide a minimum of 10% growth for future missions in terms of mounting area and overall weight. Further, by providing a separate structural panel for the mounting of the payload, flexibility is introduced to re-configure the payload in future missions without the attendant necessity of changes in the main platform. Additional power to the extent of 20% can be generated by minor augmentation to the existing solar panels. By choosing a telemetry system with variable format, its adaptability to varied mission requirements has been ensured.

The mechanical structure envisages a platform built around a central stiffened aluminium cylinder serving as the main load-bearing member. Rectangular honeycomb panels surround this cylinder and provide the configuration, the shape of a parallelopiped having dimension of 1·56 × 1·66 × 1·10 m with a payload module having the overall dimension of 0·8 m × 1·5 m × 0·5 m attached on the top. Deployable solar arrays, each consisting of three panels of 1·1 m × 1·3 m are stowed on either side of the satellite. All the subsystems of the satellite as well as the payload data handling systems are mounted on four vertical honeycomb decks. Most of the reaction control system elements including the four propellant tanks are located inside the central cylinder. The configuration of the satellite is shown in figure 7.

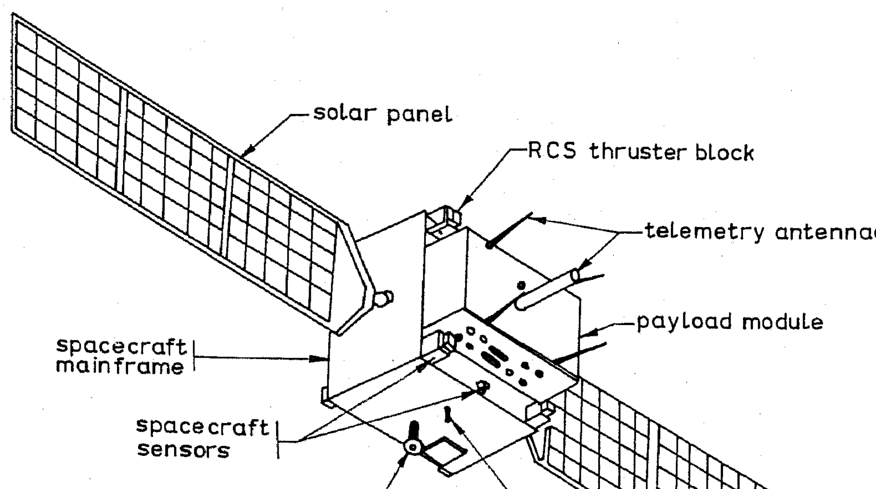

Figure 7. Indian remote sensing satellite

The thermal system of IRS spacecraft is designed with the help of passive and semiactive thermal control elements like paints, thermal blankets and heaters. The payload module requires temperature to be controlled within 15 and 25°C while battery requires a control within 10 and 20°C. All the other systems need temperature control within 0 to 40°C.

The power system consists of six-rigid deployable sun tracking solar panels along the pitch axis of the satellite with a total area of 8·5 m^2 and capable of providing 540 watts at the end of life. The power generation from solar panels is supplemented by two 40 AH nickel–cadmium batteries that keep the satellite powered in orbit night besides meeting the peak requirements during payload operation. The other components of the power system include power conditioners and power control logic circuits for the battery. The power is distributed as one regulated bus at 28 ± 1 volts and two raw busses at 16–24 volts.

The TTC system of IRS will be operating in S-band (2 to 2·3 GHz). The modulation scheme of the telemetry system is of PCM/PSK/PM type and can operate in real time and playback modes. Designed to be programmable with flexible format, the system has a frame length of 128 words and a word length of 8 bits at a bit rate of 256 bits/s in real time and 4 kilobits/s in playback. The telecommand system has a modulation scheme of PCM/FSK/PM in S-band and provides for about 350 ON/OFF commands and 20 data commands within the overall system capabilities of 511 and 63 commands respectively. An additional amplitude modulated (AM) VHF uplink with an identical onboard decoder is provided as a back-up to the S-band uplink. A S-band coherent transponder serves the communications part of the telemetry downlink and command uplink. The same transponder is used for Doppler tracking by phase locking the transmitter downlink carrier to the uplink carrier with a precise ratio of 240/221 and demodulating the ranging tones for subsequent phase modulation in the S-band downlink.

The AOCS system consists of various types of sensors for measurement of attitude errors, control electronics and different types of actuators such as reaction wheels, magnetic torquers and thrusters to impart thrusts and torques to the spacecraft in the desired directions. The heart of the attitude control system is a set of four-reaction wheels, three of which are mounted in an orthogonal triad along the pitch [±10 Newton metre second (NMS)], roll (±5 NMS) and yaw (±5 NMS) axes of the satellite. The fourth wheel (±5 NMS) mounted in a skewed fashion provides functional redundancy to the other wheels. Two magnetic torquers along the pitch and roll axes of the satellite are used for momentum dumping of the reaction wheels thereby conserving the hydrazine fuel which otherwise has to be expended for thrusting for the same purpose. A monopropellant hydrazine-based reaction control system (RCS) is used for initial attitude acquisition, correction to orbit for taking care of injection errors, maintenance of nominal orbit to ensure precise repetivity of sub-satellite track and momentum dumping of reaction wheels. The system has four hydrazine propellant tanks and two functionally redundant thruster blocks, each consisting of eight 1 Newton thrusters. With 80 kg of propellant loading, the system can provide Δv upto 180 m/s. The sensors include IR earth sensors for pitch and roll error measurements, rate integrating gyro for yaw error detection, sun sensors for pitch and yaw error measurement during acquisition and magnetometers for momentum dumping operations. These sensors enable attitude determination to an accuracy better than ±0·10°. Further, a star sensor is used to improve the accuracy of attitude estimates to better than ±0·02°.

The overall weight of the satellite is about 950 kg. The summary specifications of the spacecraft are given in table 4.

Table 4. Summary specifications of IRS-1 spacecraft

1. Overall weight	950 kg
2. Thermal control	0 to 40°C mainframe systems 20 ± 5°C payload (uses passive and semi-active techniques)
3. *Power system*	
Total solar panel area	$8{\cdot}5\ m^2$
Battery	2×40 amp-hour Ni–Cd
Bus voltages	28 ± 1 V regulated 16–24 V raw bus
Total power	540 watts at the end of life
4. TTC	
Telemetry	S-band: 2250 MHz
Modulation	PCM/PSK/PM
Telemetry rate	256 bits/s 4000 bits/s playback mode
Frame format	128 words
Word format	8 bits/word
Telecommand	S-band: 2071 MHz VHF: 149 MHz
Modulation	PCM/FSK/FM/PM
On/Off commands	342 (total available = 511)
Data commands	20 (total available = 63)
5. AOCS	
Actuators	(i) Reaction wheels: three with ± 5 NMS and one with ± 10 NMS (ii) Magnetic torquers along roll and pitch axes (iii) Monopropellant hydrazine catalytic thruster system (RCS system) Maximum fuel loading: 80 kg of hydrazine No. of thrusters: 8 each in two blocks with 1N thrust level for each thruster
Attitude sensors	(i) Infrared horizon sensors for pitch and roll measurements (ii) Dynamically tuned gyro for yaw measurement. (iii) Precision yaw sensor (iv) 4π steradian sun sensor (v) Fine sun sensor (vi) Twinslit sun sensors (vii) Magnetometers (viii) Star sensors
6. *Payload data handling system*	
Data rates	5.2 mbps for LISS-I 10·4 mbps for each LISS-II A & LISS-II B
Word length	7 bits/word
No. of words per frame	8320
Downlink frequencies	X-band: 8·3 GHz Modulation PCM/QPSK S-band: 2·2 GHz Modulation: PCM/BPSK

5. Ground segment

The ground system of IRS performs three distinct functions: (a) TTC network; (b) mission and spacecraft operations control; (c) image data reception and product generation.

Figure 8 shows the overall architecture of the ground segment.

5.1 TTC *network*

The TTC systems of the ISRO telemetry, tracking and command network (ISTRAC) will be deployed for IRS. The functions include the reception of data from spacecraft housekeeping systems in real time and playback modes, telecommanding the satellite in both VHF and S-band as well as generation of range and range rate information through tracking. Based on the link calculations for S-band TM downlink with a bit error rate better than 1×10^{-6}, a 9 m diameter parabolic dish with an overall noise temperature of about 300°K will be used. The antenna is capable of operating both in manual and auto track modes. The rest of the receiving and recording elements include preamplifier, down converter (to 70 MHz), phase-modulation (PM) and PSK demodulators, PCM bit and frame synchronizers and decommutation system.

For the S-band uplink the same 9 m dish can be used by designing the feed suitably to carry a higher power and the diplexer to isolate transmitter from receiver on ground. Telecommand rejection filter in the TM receive chain would provide the extra isolation. The ground encoder generates the PCM/FSK/FM signal which phase modulates the carrier at 2071 MHz. A VHF back-up system will be available for transmitting the commands in PCM/FSK/AM mode using a carrier of frequency around 149 MHz.

In order to provide a post-facto accuracy of better than 1 km for the subsatellite position, the tone range and two-way doppler systems are envisaged. The range and range rate tracking system, to be used for this, will be compatible with coherent phase-

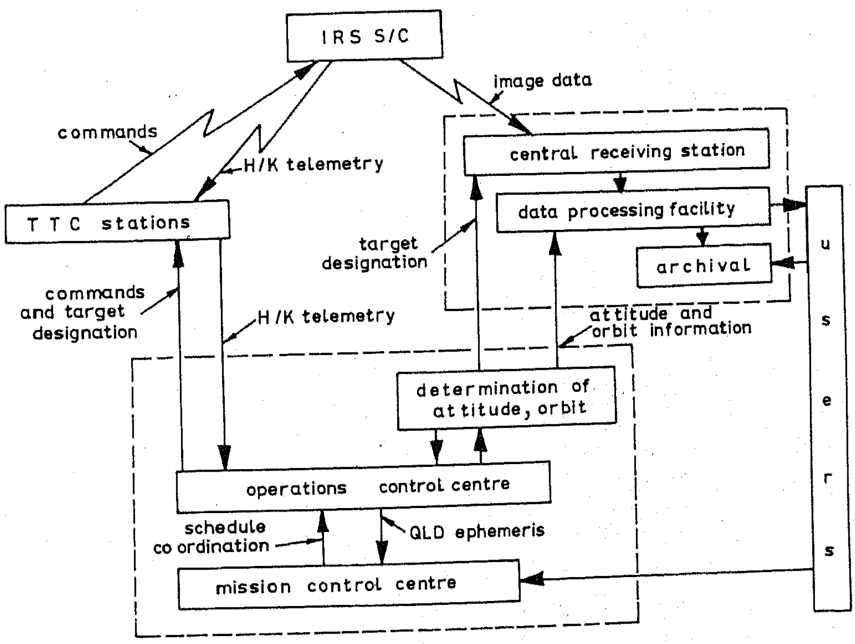

Figure 8. Ground segment architecture

locked loop (PLL) type of transponder. The uplink portion is shared by telecommand while the downlink portion is shared by telemetry, both at S-band frequencies. High accuracies for range measurements are achieved using high frequency tones (100 kHz maximum), high stability and very narrow band PLL tracking filters and doppler correction in the range processor.

5.2 *Mission operations control*

The Mission Operations Control Centre shall be the focal point for drawing up schedules for payload operations according to the user's requirements, planning the spacecraft operations and carrying out network coordination for the final implementation of such schedules. The control centre will provide target designation to the TTC network for house-keeping (HK) data acquisition, and to the image data receiving station for payload data acquisition. Further, the spacecraft health parameters are logged, processed and displayed as well as orbit and attitude determinations carried out on a daily basis at the centre. The major hardware elements include spacecraft and network control consoles, intercommunication facility, universal time display and spacecraft health status display systems in addition to supporting computer systems.

5.3 *Payload data reception*

Payload data reception system will be implemented at the National Remote Sensing Agency, Hyderabad. The station having capability for acquiring imagery data in X-band and S-band, will also have provisions for quick look display of one band imagery data of the selected camera and generating browse products. LISS-I data at 2·2 GHz and LISS-II data at 8·3 GHz are received through a single 10 m diameter antenna with a composite X/S-band feed and then amplified. The signals are down-converted to 375 MHz in X-band and 75 MHz in S-band. The down-converted signals are QPSK demodulated in X-band and BPSK demodulated in S-band. The data are recorded in high density digital taperecorders and also fed to quick look display (QLD) system for selected on-band display.

5.4 *Data products*

The data is converted into a variety of data products such as high density digital tapes (HDDT), 70-mm film, microfische, 240 mm black and white as well as colour prints, computer compatible tapes (CCT) and false colour composites (FCC) by four different levels of processing. At level-1, browse products are generated in the form of HDDT and film negatives for all the bands of all cameras after eliminating the cloud covered areas through quick look data. This product will be corrected for radiometric and earth rotation effects, annotated and will be available with a nominal turn around time of 3 days. Standard products are generated at level-2, that are corrected for sensor, scene and platform-related geometric effects. The turn-around-time for the availability of this product in the form of CCT or photographic products is 7 days. At level-3, precision products are generated with a turn around time of 3 weeks having refined registration using ground control points. Special product, at level-4, use standard products on CCT as inputs and are generated for specialized user needs for specific applications. Figure 9 illustrates the sequential flow of data product generation function.

The data products systems include image processing computers, special photographic laboratories equipped with systems for processing, developing and printing of both black and white and colour photographs and sophisticated recorders like laser beam recorder.

7. Compatibility and complementarity of IRS with other remote sensing satellites:

Whereas data from IRS-1 will be able to meet the requirements of a broad class of application goals already enumerated earlier, a limited number of specific resource studies can be more effectively undertaken using the data of IRS-1 in conjunction with other satellites such as LANDSAT-D and SPOT (a French remote sensing satellite). In the context of the spatial resolution, the 73 meter data of LISS-I besides ensuring continuity of data for the users of LANDSAT 1, 2 and 3 should also enable multistage sampling analysis when used together with that from LISS-II (37 m), LANDSAT-D (30 m) and SPOT (20 m) with aircraft flights providing further supplementary information at 10 m level. The spectral bands chosen for IRS-1 are close to those of the first four bands of the thematic mapper on-board LANDSAT-D and also to those provided in SPOT. Further, for supplementary information on thermal IR, data from LANDSAT-D can be used. Further, to evaluate the potential of higher radiometric quantizing levels, particularly for crop-stress studies, the data of IRS-1 at 7 bits can be used with those available from LANDSAT 1, 2 and 3 (6 bits) as well as from LANDSAT-D (8 bits) and SPOT (8 bits). Multiple satellite systems, if concurrently used, could also reduce the coverage cycle for a particular geographic location. The X-band and S-band communication systems chosen for IRS-1 are compatible with LANDSAT-D and SPOT frequencies enabling the use of common

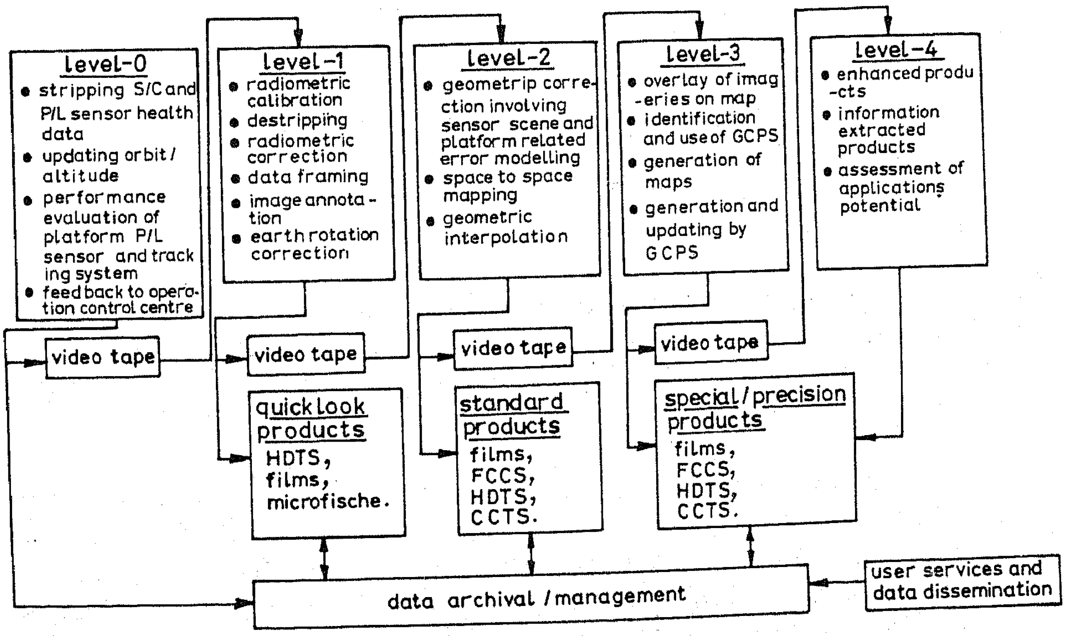

Figure 9. Generation of data products

ground data reception terminals. The approach to data product generation is also planned to be similar to that for LANDSAT-D and SPOT enabling users to employ the data from all these satellites with minimal processing for normalization.

7. IRS utilisation programme

A comprehensive utilisation programme has been drawn up for the effective utilisation of data likely to be available from the proposed Indian remote sensing satellite (IRS-1) keeping in view the Indian experience in the application of remote sensing technique to natural resources survey and the overall specifications of the IRS-1 satellite system (IUP Report 1982). IRS-1 utilisation is considered as the transition from the experimental applications to operational usage. The main objectives of the IRS-1 utilisation programme (IUP) are:

(i) to use the IRS-1 data for applications in selected areas of resource management, *viz* agriculture, hydrology, geology and the environment.
(ii) to transfer the technology of applications to the user agencies and to develop an infrastructure which would support the future ongoing remote sensing based information system in the country and
(iii) to provide inputs for the IRS-1 follow on programme.

7.1 *Applications envisaged under* IRS *utilisation programme*

The application projects for the utilisation of the IRS data have been considered keeping in view the unique character of remotely-sensed data, their potential in providing reliable, timely and comprehensive data base for the effective management of national natural resources and the themes suggested by the Preparatory Committee of National Natural Resources Management System (NNRMS). In arriving at these projects, the major considerations have been

(i) utility, *vis-a-vis*, the national natural resources management system and the long-term perspective
(ii) IRS-1 system and its capabilities
(iii) IRS-1 sensors and their capabilities in terms of spatial resolution, spectral bands, etc.
(iv) Expertise and infrastructure available in the country
(v) Past experience in remote sensing and in particular, various experiments carried out under the joint experiments programme (JEP) and the end-to-end experiments under NNRMS.

The major application areas where IRS-1 can make important contributions are: (i) agriculture and land use; (ii) forestry; (iii) geology (mineral resources); (iv) water resources; (v) environmental studies (vi) marine resources and (vii) cartography.

Though most of the applications considered are expected to be potentially feasible, there may be certain limitations in the full realisation of these during the IRS-1 phase. For example, in agriculture, an additional spectral band in the spectral range

1·55–1·75 μm would have been most useful in the moisture-stress detection. The availability of stereo-coverage, spectral bands in the 1·55–1·75 and 2·1–2·3 μm range and in the thermal infrared region would have been extremely useful in geological applications. For applications in marine resources, narrower spectral bands and higher signal-to-noise ratio would have been useful.

In view of the main objective of operationalisation of remote sensing applications it is considered desirable to categorise various applications before converting them into projects on the basis of the status of technology and the Indian experience. The application projects thus considered fall into four categories: (a) operational application projects (OAP); (b) quasi-operational application projects (QAP); (c) experimental application projects (EAP); and (d) technique development projects (TDP).

OAPS are those where remote sensing technology has been demonstrated successfully. These can be adopted by the users on an operational basis. QAPS are those in which the practicability of the application is demonstrated on a pilot scale. EAPS aim at establishing the feasibility to use remote sensing technology for specific applications. Classification of projects under this category assumes that the technology development tasks have been completed and the possibility of using remote sensing techniques have been established. TDPS start with identification of the information needs of the potential users of remote sensing technology applications. They aim at formulating a hypothesis and providing the hypothesis through laboratory and limited field experiments. A successful TDP would establish the possibility of using remote sensing technology to extract the required information. Development of subsystem level techniques is also classified under TDP. Figure 10 illustrates the concept of different applications and users involvement. Table 5 lists the application projects identified under different categories under IUP.

The application projects described above form the core of the applications programme. Depending upon the users interests, needs and the feasibility, specific applications other than those mentioned above may also be taken up.

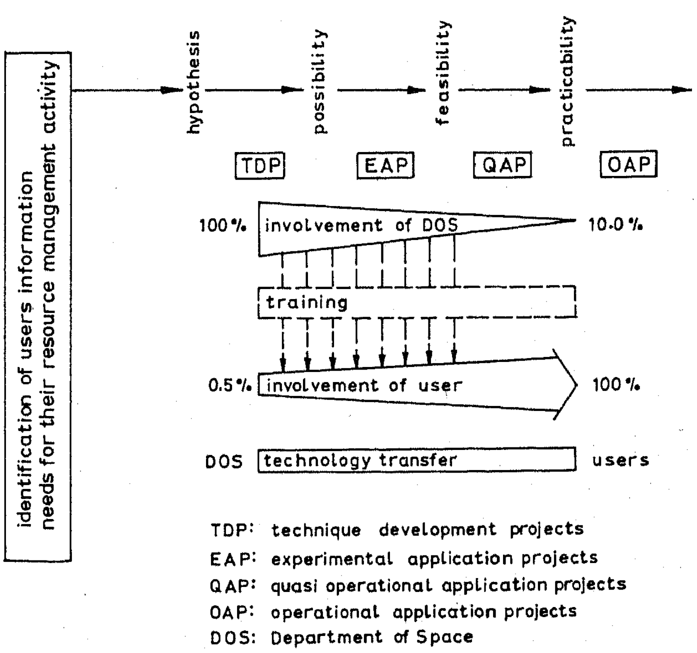

Figure 10. Operationalization of remote sensing-based resource information system

Table 5. IUP-application projects

Category	Application projects
1. Operational appliction projects	1.1 Flood mapping
	1.2 Groundwater exploration
	1.3 Regional geological mapping
2. Quasi-operational application projects	2.1 Soil mapping
	2.2 Drought monitoring
	2.3 Land use/land cover mapping
	2.4 Land degradation including desertification
	2.5 Snow mapping
3. Experimental application projects	3.1 Crop production forecasting
	3.2 Forest mapping and damage detection
	3.3 Water quality monitoring
	3.4 Watershed characterisation
	3.5 Monitoring of coastal environment
	3.6 Marine fisheries
4. Technique development projects	4.1 Crop yield modelling
	4.2 Crop stress

7.2 IRS *utilisation, vis-a-vis* NNRMS

IRS utilisation programme is expected to provide significant inputs to the remote sensing-based information system in the framework of NNRMS as outlined by Dasgupta *et al* (1983). The concept of the IRS utilisation programme and its relationship with the NNRMS are illustrated in figure 11. Among the different projects mentioned above, the operational and quasi-operational application projects are expected to yield information to the resource managers which could act as working experience in using this type of information for resources management. As the scope of IRS utilisation programme increases and with the launching of more sophisticated and application specific satellites, remote sensing-based information in other application areas would also contribute to the NNRMS.

7.3 *Methodology of data analysis*

Given a data product in the form of an image or a computer compatible tape, to extract useful information from it for final end utilisation in a particular application area would require various stages of data analysis specific to each application area. Details of mode of analysis may be to a certain extent dependent upon the individual scientist. However, broad methodology exists for each. The project groundwater exploration drawn from the OAP category and the project crop production forecasting drawn from the EAP category will be illustrated from this viewpoint.

7.3a *Groundwater exploration* Groundwater by its very nature is not directly discernible from satellite images. What one intends to do is to identify areas which are potential for groundwater occurrence. Use of LANDSAT images for identification of such areas has been successfully demonstrated in many experiments carried out by Sahai *et al* (1982)

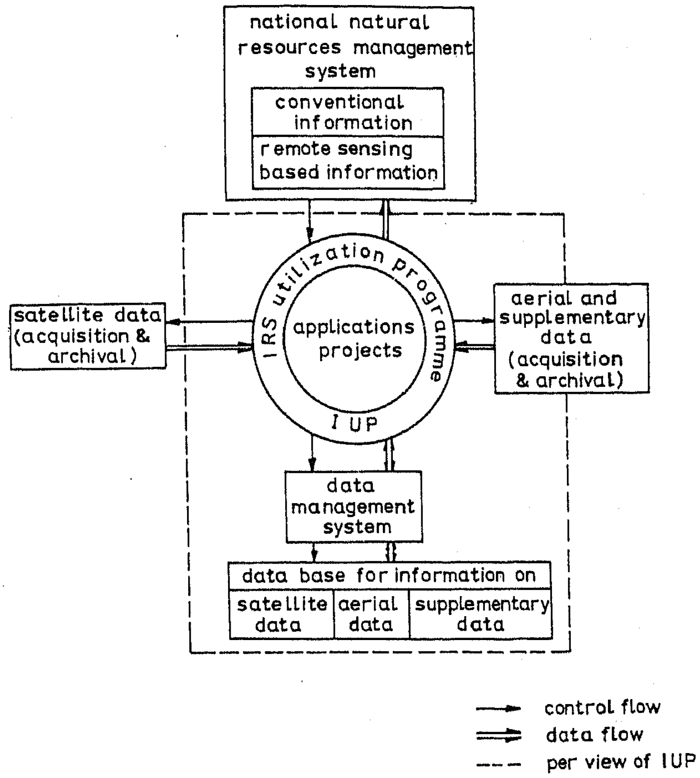

Figure 11. IRS utilization programme and its linkage with NNRMS

and Moore (1977). IRS-1 images with better spatial resolution and with spectral bands more specific for vegetation mapping should prove quite useful in groundwater exploration. The broad procedure could be as follows: (i) Identify drainage characteristics, surface water bodies, vegetation types and delineate land forms in the area of interest. (ii) Prepare a lineament map showing faults, fractures, dykes, arcuate features, lineament intersections, etc. (iii) Attempt correlation of features identified on the images with available well inventory data and do field checks. (iv) On the basis of the above mentioned information, the hydrologist would identify areas for further geophysical investigations making use of his expertise. (v) On the basis of results obtained from geophysical investigations, one selects sites for bore hole drilling, further development and exploitation. Time of year is also critical for obtaining maximum hydrologic information from satellite images. Under our conditions, one may have to study atleast two sets of images, one corresponding to the pre-monsoon period and the other pertaining to the post-monsoon period. If available, one may study low sun elevation angle images for enhancement of certain geomorphological features which have bearing on groundwater occurrence.

7.3b *Crop production forecasting* Crop production forecasting, advance of harvest, is very vital for the national economy. This requires estimating the total area under that crop and its yield determination. A very successful experiment in this regard using LANDSAT imagery/data is the large area crop inventory experiment (LACIE) conducted by the National Aeronautics and Space Administration in collaboration with other US Agencies. The methodology adopted in LACIE may not be directly applicable under Indian conditions because of (i) smaller land holdings, (ii) mixed cropping pattern,

(iii) different cultural practices, and (iv) variability in crop calendar.

A possible crop production estimation methodology envisaged using IRS-1 data in conjunction with aircraft and ground data employing multi-stage stratified random sampling technique is as follows:

(i) The cropped area may at the first step be stratified into homogeneous areas on the basis of high resolution satellite data. Apart from IRS-1 LISS-II data, data available from SPOT and other contemporaneous satellites may be used. This is quite essential since the repetivity of IRS-1 is 22 days, rather infrequent from this application point of view.
(ii) In each of these homogeneous areas, sample segments may be chosen for conducting aerial surveys with sensors compatible with sensors on board the satellite.
(iii) Detailed ground truth data collection.
(iv) Signatures of crops at different growth stages be extracted to do multispectral analysis and unique identification of crops.
(v) Using clustering algorithms, estimate acreage.

For determining yield per unit area, development of spectro-agrometeorological models is necessary. The advantage of such models would be that spectral data of crops is a manifestation of the integrated effects of weather, soil and cultural factors. However, this developmental activity is a long-lead task. So, at present, one has to go in for crop-cutting experiments done on a sample basis for yield determination.

8. IRS-1 follow on programme

An important component of the IRS programme is the IRS-1 follow-on activity. This programme has to cater to the following important aspects: (i) Continuity of service to users in certain operational application areas. (ii) Provide sensors on-board the future satellites with improved specifications to refine and widen the scope of utilisation. (iii) Cater to new application areas not considered hitherto.

IRS-1 represents the first of a series of operational remote sensing satellites that will serve the user needs in resources survey. IRS-1A is configured with adequate growth potential in terms of weight, power, telemetry, etc. This should enable incorporation of payloads with improved specifications. Figure 12 illustrates IRS series concept.

IRS-1 is basically a satellite meant for land-based applications although data can be used for certain marine resource related/coastal environment applications. More specifically IR spectral bands are required for chlorophyll estimation, a pre-requisite in marine fisheries. Higher signal-to-noise ratio and higher quantization levels are also required since the ocean signal is very small. Spatial resolution requirement is not very critical in this application. Sea surface temperatures, wave spectrum data, etc., are also required to be known for which microwave sensors are essential. These factors are not necessarily compatible with requirements of a land-based application satellite. Hence, a separate satellite meant for marine application may have to be proposed.

There are many other application areas which demand improved spatial resolution and spectral bands in other regions of the electromagnetic spectrum. Geological studies require spectral bands in the middle infrared, thermal region and also require stereo

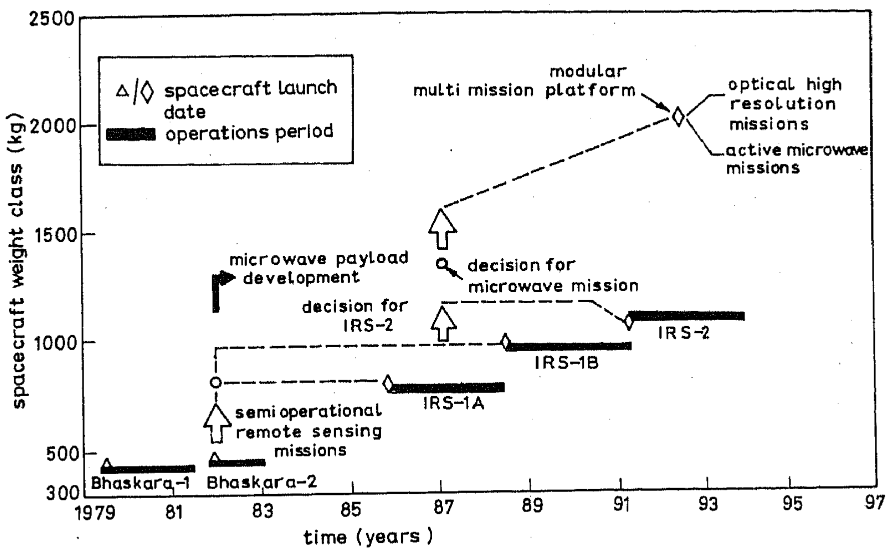

Figure 12. IRS series concept.

coverage. Snow/ice mapping requires a spectral band in the region 1·55–1·75 μm for differentiating snow and cloud. Better repetivity is essential for snow-line monitoring.

Soil moisture detection and quantification is crucial in many agricultural applications. This would require microwave sensing. Crop production forecasting is another important application area in which improved spatial resolution, spectral bands in the middle infrared and better repetivity would help in realising the objectives of the application. One could also say that the future satellites in the IRS series have to become application-specific as in marine resources and/or have improved spatial resolution, better repetivity, more specific spectral bands, etc for broadening the scope of utilisation. However such improvements will lead to larger data rates to be handled and thus calling for large scale manpower and computer resources. One way of getting over such a problem appears to be to introduce certain preprocessing of data onboard the satellite itself. The SMART sensor onboard the *Rohini* satellite RS-D2 launched on 17 April 1983 can be considered as a good example in this direction. Such a sensor can in principle identify and if necessary eliminate information not relevant to the envisaged applications (such as cloud cover).

9. Concluding remarks

IRS mission represents the first major step in developing the operational capability in the area of resource surveys from space in India. The IRS-1A project envisages building structural and engineering models of the space segment in the time-frame of 1983–84 followed by the fabrication and testing of two flight-worthy models in the subsequent two years. The launch of IRS-1A is slated for the time frame of late 1985/early 1986.

The data reception and other elements of the ground segment will be set up parallely during the same time-frame.

A comprehensive programme has been drawn up in collaboration with various users, for effective utilization of available data. The programme envisages various application projects, setting up of regional remote sensing centres, development of equipment and material, etc. The programme is to play a key role in the evolution of a national natural resources management system.

The details presented in this paper are based on information generated at the different centres of ISRO and at NRSA who are involved in the IRS programme. One of the authors (RRN) wishes to acknowledge the kind encouragement given by Prof. P D Bhavsar, during the preparation of this manuscript.

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