Indian remote sensing satellite (IRS)-1C—The beginning of a new era

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THE varied advantages of satellite remote sensing in effectively harnessing the available natural resources potential, have been successfully utilized in many parts of the world. The unique capability of space-based sensors to provide a wide range of information available in the electromagnetic spectrum, in a synoptic and more frequent manner, has made this technology an inevitable tool in the sustainable development and utilization of our natural resources. The Indian remote sensing community, who used data obtained through Hassleblad camera as the information source in the late sixties is now being provided with satellite data which is beyond comparison with the former. The Indian remote sensing satellite, IRS-1C, which is the latest addition to the remote sensing satellite family, is considered to be the most advanced, compared to other contemporary satellites in the world, mainly by virtue of its capability to provide high resolution data and more frequent coverage from a unique combination of sensors.

Indian remote sensing programme: The growth towards excellence

In India, development of satellite platforms for acquisition of remotely sensed data began with the Bhaskara mission of late seventies. The Bhaskara satellites had a two-band TV payload for land applications and a Satellite Microwave Radiometer (SAMIR) for oceanographic/atmospheric applications. The spatial resolution of the TV payload imageries was about 1 km whereas the SAMIR data were with 'footprints' of about 125 km. 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 related to the integration of remotely sensed data with conventional data systems for resource management.

Convinced of the capabilities and the inevitable role of satellite remote sensing in national development, India embarked upon several Joint Experiment Projects (JEP) with the active involvement of the user community for the optimal management of our natural resources. Subsequently, the National Natural Resource Management System (NNRMS), a unique organizational set up in the world, was established to ensure the most effective utilization of remote sensing technology by facilitating the establishment of necessary space, ground and user segments as well as the integration of the views of the administrators, decision makers, technologists and user community. This resulted in successful launch and operationalization of IRS-1A in 1988. Compared to Bhaskara, considerable progress had been achieved in every aspect of the satellite mission. Subsequently, IRS-1B and IRS-P2 satellites were launched in 1991 and 1994 respectively. These missions have not only realized the primary objective to design, develop and deploy a three-axis stabilized polar sun-synchronous satellite carrying near state-of-the-art payloads, but also paved the way to establish and routinely operate ground-based systems for spacecraft data reception, dissemination and analysis and mission control facilities, ensuring the operationalization of the programme on an end-to-end basis.

Commensurate with the developments in satellite technology and data availability (Table 1 *a* and *b*) considerable progress has been made towards effective utilization of the available data for various applications. Since the days of macrolevel assessment of coconut wilt disease using Hassleblad camera, remote sensing applications have come a long way in our efforts towards sustainable resource management. Today this technology has been operationalized to cover diverse themes/areas such as forestry, agricultural crop acreage and yield estimation, drought monitoring and mitigation, flood monitoring and damage assessment, landuse/cover studies, wasteland identification and reclamation, water resources development and management, groundwater targeting, marine resources survey, urban planning, mineral prospecting, environmental impact assessment and so on – thus encompassing almost every facet of sustainable resource development and management (Figure 1).

Utilization of remote sensing technology for resources mapping and monitoring apart, the remote sensing appli-

Table 1 *a*. Characteristics of Indian satellites for earth observation

Parameters	Bhaskara-I & II	IRS-1A/1B	IRS-1C/1D
Class	Spin-stabilized	3-axis stabilized	3-axis stabilized
Weight (kg)	444	975/989	1247
Power (W)	47 W from solar panels and Ni–Cd batteries	709 W from solar array (EOL) 2 Ni–Cd batteries	813 W from solar array (EOL) 2 Ni–Cd batteries
Mission life	One year	Three years	Three years
Launch	1979, 1981	1988/1991	1995
Orbit			
Height (km)	Apogee 557 Perigee 572	904	~817
Inclination (deg)	50.7	99.028	98.12
Type	Near circular	Sun-synchronous	Sun-synchronous
Equator crossing time		10:25	10:30
Repetitivity (days)	–	22	24

Table 1 *b*. Characteristics of remote sensors on board Indian satellites for earth observation

	Bhaskara I/II TV	Bhaskara I/II SAMIR	IRS-1A/1B LISS-I/II	IRS-1C/1D LISS-III	IRS-1C/1D PAN	IRS-1C/1D WiFS
Type	TV camera	Dick-type microwave radiometer	CCD camera	CCD camera	CCD camera	CCD camera
Spectral bands (μm)	0.54–0.66 0.75–0.85	19, 22, 31 (GHz)	0.45–0.52 0.52–0.59 0.62–0.68 0.77–0.86	0.52–0.59 0.62–0.68 0.77–0.86 1.55–1.70	0.5–0.75	0.62–0.68 0.77–0.86
Ground res. (m)	1 km	125 km	73/36.5 (foot print) 148/2 × 74	~23 (VNIR) ~70(MIR) ~140	5.8	188
Swath (km)	~341	–	148/2 × 74	~140	~70	810
Steering	Nadir	Nadir	Nadir	Nadir	Steerable ± 26°	Nadir-looking

cations scenario has witnessed a phase transition from resource mapping to decision making. The capability of this technology to provide a wide range of details in a holistic, synoptic and unbiased manner as well as the possibility to obtain these information on a periodic basis has facilitated this transition. For example, the accelerated pace of surveying and monitoring activities have formed the basis of strategic planning and policy formulation at different levels of decision making. While major decisions on the contingency plan, water release from reservoir and buffer stock of food grains can be ascribed partly to the inferences drawn from remote sensing-based fortnightly drought monitoring and preharvest estimation of acreage and yield in respect of major crops in the country, the groundwater potential maps for the entire country, prepared during late eighties have been the major source of information that contributed to the tremendous success of drinking water technology mission. Similarly there are a number of examples such as monitoring of forest encroachment, setting up of chemical industries, realization of environmental integrity, establishing infrastructural facilities, water resources management, policy formulation for urban environment, disaster management, etc. where remote sensing-based information is used as an invaluable aid in decision making.

IRS-1C: The genesis

While acknowledging the fact that high level of operationalization has been attained in a number of application areas, it was felt that efforts have to be made to consolidate the gains achieved so far, as well as to increase the application of satellite remote sensing in those areas where the technology has tremendous potential but remains only partially utilized at present. Besides, an earnest attempt is inevitable to explore the capability of remote sensing in new areas which are not yet amenable to it; but could be within our reach. The advances in electro-optics, detectors and signal processing onboard with corresponding developments in data processing and

Today . . .

- **Forest**
  Forest mapping
  Forest fire detection
  Grassland mapping
  Shifting cultivation
- **Agriculture**
  Crop inventory
  Soil classification
  Saline/alkaline soil mapping
  Wasteland delineation
  Landuse/cover mapping
  Drought monitoring
- **Water resources**
  Surface water inventory
  Snow-melt run-off
  Watershed characterization
  Irrigation water management
  Multipurpose river valley projects
  Flood inundation mapping
- **Geology**
  Groundwater targeting
  Geological mapping/mineral targeting
  Pipeline/road alignment
- **Environment**
  Urban sprawl
  Land degradation
  Mining impact
  River action plans
  Volcano monitoring
- **Coastal/ocean**
  SST generation
  Fishery forecast
  Coastal zone mapping

Tomorrow . . .

Crop yield, stress detection
Pest/disease surveillance
Soil moisture estimation
Oil pollution monitoring
Ocean dynamic parameters
Ocean productivity/improved fishery forecast
Impact of sealevel rise
Precipitation estimation
Forest stock/species
Forest timber volume
Biodiversity
Biomass estimation
Cadastral mapping
Digital terrain modelling
Natural resources management models

Figure 1. Remote sensing application scenario.

analysis on ground, have enabled planning for very high spatial resolution payloads to cater to mapping at scales larger than 1 : 10,000. Consequently, it is recognized that the satellite remote sensing capabilities will henceforth start addressing even applications hitherto in the domain of aerial photography. These apart, the Indian remote sensing programme should not only be able to meet the national needs but also be in tune with emerging international scenario. These thoughts have paved the way for the conceptualization of the second generation Indian remote sensing satellites, IRS-1C/1D.

The basic requirements of the user community which were to be addressed in IRS-1C/ID were the following:

a) Continued availability of multispectral data, similar to LISS-I and LISS-II data of IRS-1A, 1B and P2, but with better spatial resolution.
b) Availability of data in the shortwave infrared region, especially for agricultural applications.
c) Panchromatic data with spatial resolution better than 10 m as well as the capability to have stereoimages for cadastral applications.
d) Availability of data with high repetitivity and wide swath; but with a spatial resolution which is better than that of NOAA.
e) A mission that can meet the data requirements of the international community as well.

Besides, an analysis of the application scenario *vis-à-vis* the user requirements has clearly brought out the need to have application specific, low-cost missions which can provide data, especially for studies related to certain thrust/gap areas of applications. It is widely accepted that there is a need to have very high spatial resolution data for cartographic applications such as generation of cartographic database, digital elevation models, cadastral level developmental plans, etc. While these missions could address land and water-related applications, there have been demands from the user community for fullfledged missions, addressing various parameters of relevance to oceanography as well. Also, in view of the increased global efforts towards better understanding of the environment and implementation of action plans identified under Agenda 21, aimed at protection of planet Earth, it becomes essential to have data for various environmental studies. Based on these observations a few more satellite missions called IRS-P series, are being considered to be realized using the launch opportunity, provided by PSLV developmental/continuation flights. IRS-P series of satellites are expected to be low-cost, quick turn-around, application specific missions that can cater to a majority of the application needs in specific gap areas. These missions could be viewed as complementary/supplementary to operational missions and as opportunities for proving technology and applications with new payloads and instruments. The IRS-1C, with a unique combination of imaging sensors, could be considered as the beginning in this direction.

IRS-1C: The beginning of a new era

The IRS-1C marks a new beginning in the global efforts towards effective utilization of remote sensing technology for natural resources management. IRS-1C, with a unique combination of payloads as well as capabilities and the resultant application potential is considered as the best civilian remote sensing satellite, launched by any spacefaring nation so far (Table 2). Also, for the first time an Indian remote sensing satellite has been designed as a global mission and efforts are underway to ensure the availability of data all over the world by establishing a network of ground stations.

The mission

The IRS-1C satellite, weighing around 1250 kg is placed in a polar sun-synchronous orbit of 817 km with the local time of equator crossing at 10:30 h. The satellite takes 101.35 min to complete one revolution around the earth and completes about 14 orbits a day. The entire Earth is covered by 341 orbits, during a 24-day cycle.

In view of the requirements arising out of the high resolution imaging sensors, stringent specifications have been drawn for the attitude characteristics of the platform. The pointing accuracy, the drift rate and jitter specifications of the platform have been finalized after taking into consideration the requirements of the precision processed, geometrically corrected images.

To meet the stringent thermal and alignment stability requirements of the payloads, the payload platform is separated from the top deck of the main platform by a CFRP cylinder. The payload platform, besides accommodating the payloads, also accommodates the earth sensors and the star sensors, taking care of the look angles and FOV clearances. The earth sensors and star sensors are placed on the common payload platform to minimize alignment instability between them and the payload cameras due to thermal distortion of the satellite structure.

The Attitude and Orbit Control System (AOCS) is basically configured around a zero-momentum system using a four reaction wheel configuration. The attitude control system consists of the attitude measurement sensors (sun sensors, earth sensors, star sensors, DTG), the control logic and the actuators. Figure 2 shows the artistic view of IRS-1C spacecraft and Table 3 gives the salient features of the spacecraft system.

The payloads – A unique combination

IRS-1C offers the remote sensing community a unique combination of payloads consisting of three cameras: one operating in the panchromatic and the other two in the multispectral bands (Table 4). These payloads that operate in push-broom scanning mode using Charge Coupled Devices (CCD) as detectors are unique in terms of their resolution, revisit period and application potential.

Panchromatic camera (PAN). The panchromatic camera enables the acquisition of images at a resolution of 5.8 m which is the highest spatial resolution being offered by any civilian remote sensing satellite, presently orbiting the earth. The PAN camera operates in the spectral range of 0.5–0.75 μm and provides a ground coverage of 70 km. The camera has off-nadir viewing

Table 2 IRS-1C *vs* other major satellite missions

Capability	Landsat (USA)	SPOT (France)	IRS-1C (India)
Sensors			
Panchromatic	x	✔	✔
Multispectral	✔	✔	✔
Wide-field	x	x	✔
Stereo	x	✔	✔
Resolution (m)			
Panchromatic	–	10	5.8
Multispectral	30	20	23
Wide-field	–	–	188
Swath (km)			
Panchromatic	–	60	71
Multispectral	185	60	141
Wide-field	–	–	810
Coverage	Global	Global	Global

Figure 2. An artistic view of IRS-1C in space.

capability with a revisit frequency of 5 days which can provide stereo images. A payload steering mechanism supports and rotates the PAN camera to a pre-determined angle in the pitch-yaw plane with the maximum scan-range being $\pm 26°$. This corresponds to an off-nadir coverage of ± 398 km on the ground.

Linear Imaging Self Scanner (LISS-III). The four band multispectral camera, LISS-III provides the data of the earth's surface in the shortwave-IR region besides visible and near IR regions of the electromagnetic spectrum. LISS-III has a spatial resolution of 23.5 m each in the visible and near-IR bands and 70 m in the shortwave IR band. The swath in the visible and near IR bands is 141 km while the SWIR has a swath of 148 km. Each band has its own collecting optics and linear array CCD. The electro-optic modules are maintained at $20 \pm 3°C$.

Wide field sensor (WiFS). WiFS is a two-band camera which enables the dynamic monitoring of natural resources and observes the same region once in every five days. The two bands operate in the visible and near IR region with a spatial resolution of 188.3 m and a wide swath of 810 km. Two lens assemblies are provided for each band with a view to minimizing the spectral and geometric inaccuracies due to wide field optics.

Improved capabilities – Newer applications

The unique combination of data available from IRS-1C, covering different regions of the electromagnetic spectrum, is expected to cater to the varied requirements of the remote sensing community, leading to newer applications. Use of high resolution data along with the stereo-viewing capability available from PAN camera enables the generation of detailed digital cartographic database and digital terrain models which can help in arriving at engineering solutions to complex problems

Table 3. System features

Mechanical	
Structure	Aluminimum/aluminium honeycomb with FRP elements
Thermal system	Passive/semi-active thermal control with paints, MLI blankets, OSRs and closed loop temperature controllers
Thermal control	Payloads : $20 \pm 3°C$ SWIR : $-10 \pm 0.15°C$ Battery : $2 \pm 2°C$ Electronics : 0 to 40°C
Mechanism	Solar panel deployment; PAN hold down release
Power systems	
Solar panels	9.636 m^2 rigid, sun tracking type, generating 813 W power at EOL, at normal incidence.
Chemistry battery	2×21 AH Ni–Cd batteries
Power electronics	Two raw buses 28–42 V supplying power to all sub-systems
AOCS system	
Sensors	Earth sensors, sun sensors, magnetometer and gyros. Star sensor for post facto attitude determination
Actuators	Reaction wheels, magnetic torquers, hydrazine thrusters (1 N and 11 N)
AOCE	Microprocessor-based system with hardwired backup system
Pointing accuracy	$\pm 0.15°$ (pitch and roll) $\pm 0.20°$ (yaw)
Drift rate	$< 3 \times 10^{-4}$ deg/sec.
Telemetry	House keeping information in S-band; PCM/PSK/PM modulation, real time/dwell rate 512 bps and playback/star sensor data 6.4 Kbps, onboard storage (HK) capability 2.75 Mb
Telecommand	S-band; PCM/FSK/FM/PM with facility for ON/OFF and data commands
Tracking	S-band tone ranging and two way doppler X-band beacon

Table 4. Imaging sensors characteristics

Panchromatic		
Spatial resolution (m)	5.8	
Swath (km)	70	
Spectral band (μm)	0.5–0.75	
CCD device	4096 elements linear array	
Device size (micron)	7×7	
No. of quantisation levels (bit)	6	
SNR (at saturation radiance)	> 64	
SWR (at Nyquist frequency)	0.20	
Integration time (msec)	0.883	
Data rate (Mbps)	84.903	
Linear imaging self-scanner-III	Visible	SWIR
Spatial resolution (m)	23.5	70.5
Swath (km)	142	148
Spectral bands (μm)	0.52–0.59 0.62–0.68 0.77–0.86	1.55–1.70
CCD device	6000 element *linear array*	2100 element *linear array*
Device size (μm)	10×7	30×30
No. of quantisation levels (bit)	7	7
SNR (at saturation radiance)	> 128	> 128
Band-to-band registration (pixels)	± 0.25	
SNR (at Nyquist frequency)		
(0.52–0.59 μm)	> 0.40	
(0.62–0.68 μm)	> 0.40	> 0.30
(0.77–0.86 μm)	> 0.35	
Integration time (msec)	3.5528	10.6584
Data rate (Mbps)	35.790	1.3906
Wide field sensors		
Spatial resolution (m)	188	
Swath (km)	810	
Spectral bands (μm)	0.62–0.68 0.77–0.86	
CCD device	2048 elements linear array	
Device size (μm)	13×13	
No. of quantisation levels (bits)	7	
SNR (at saturation radiance)	> 128	
SWR (at Nyquist frequency)	> 34 (0.62–0.68 μm) > 20 (0.77–0.86 μm)	
Integration time (msec)	28.4224	
Data rate (Mbps)	2.0616	

associated with microlevel planning and development. The high resolution PAN data can also provide reasonably accurate Digital Elevation Models (DEM) which could pave the way for terrain mapping and generation of contour maps with smaller intervals. The capability to provide high resolution stereo images with a revisit frequency of 5 days is expected to open up new vistas in urban management even to the extent of understanding the population dynamics and utilities planning. Added to these are the potential of PAN data for the updation of existing topographical maps as well as mapping at cadastral level.

The LISS-III camera onboard IRS-1C provides data in the visible, near-IR and shortwave IR region. While the SWIR data are of immense help to study crop canopy water status and estimation of leaf area index, data from visible and NIR bands with a resolution of 23.5 m are expected to significantly improve the separability amongst various crops and vegetation, leading to identification of small fields and better classification accuracy. The LISS-III data can also be effectively utilized for discrimination of crops in the mixed crop regions and mapping of various thematic information with greater details.

The high repetitivity data available from WiFS payload in two spectral bands will help in the monitoring of natural resources, especially the vegetation and dynamic phenomena like floods, droughts, forest fires and so on. Other major applications include the monitoring of crop vigour and health, cropping pattern, crop rotation, progress of harvest, etc. The availability of data with a five-day repetitivity enables generation of spectral growth profiles at almost every stage of a crop. No doubt, the high repetitivity data with wider ground coverage from WiFS will provide excellent opportunities in the areas of natural resources monitoring at regional and global level.

Data dissemination and utilization

The images acquired by IRS-1C are being disseminated to a wide spectrum of users to meet their specific requirements. Keeping in mind the varied interests of the user community, a variety of data products are available to users from different sensors of IRS-1C. While the NRSA Data Centre at Hyderabad is the focal agency for user interfaces, the EOSAT Company of USA who holds the marketing rights for IRS-1C, supplies data to the international user community. A network of ground stations is being established in different parts of the world to facilitate easy dissemination of data.

Establishment of necessary ground infrastructure to ensure effective utilization of data for various applications at different levels has been an integral component of the Indian Remote Sensing Programme. Necessary infrastructure facilities have been established in different parts of the country. Apart from National Remote Sensing Agency, Hyderabad and Space Applications Centre, Ahmedabad a chain of Regional Remote Sensing Service Centres and State Remote Sensing Centres with well-equipped facilities for data analysis and utilization, caters to a large spectrum of the user community. Besides, a number of centre/state departments/agencies and private organizations have also set up facilities towards effective utilization of satellite data in the country.

Conclusions

Remarkable developments in space technology and its applications have contributed significantly towards sustainable utilization of our natural resources. The Indian Remote Sensing Programme which had a modest beginning in the late sixties has grown into a matured and well-balanced programme by realizing state-of-art space, ground and user segments, leading to an end-to-end capability. IRS-1C, the latest addition to the remote sensing satellite family, is considered as the best civilian remote sensing satellite launched by any spacefaring nation, so far. In view of the diverse requirements of a wide range of users in India and abroad, a variety of data products are being made available from different sensors of IRS-1C and are being disseminated all over the world by a network of ground stations. The continued data requirements of the user community will be supplemented when IRS-1D is launched in 1998. These apart, the IRS-P series of satellites, proposed to be launched using the developmental flights of Polar Satellite Launch Vehicle (PSLV) will provide further impetus in realizing the data requirements of the remote sensing community. The IRS-P series of satellites are application-specific, low cost and quick turn-around-time missions with the objective to provide data for thrust areas of application, including cartography, oceanography and environmental studies. No doubt, the varied advantages of IRS-1C/1D by virtue of their unique payloads, capabilities as well as application potential, along with the proposed IRS-P series of satellites will usher in a new era in the global efforts towards sustainable utilization and management of our natural resources.