Proc. Natl. Acad. Sci., India, Sect. A Phys. Sci. (October–December 2017) 87(4):465–472
https://doi.org/10.1007/s40010-017-0428-8

EDITORIAL

Satellite Remote Sensing: Sensors, Applications and Techniques

P. S. Roy[1] · M. D. Behera[2] · S. K. Srivastav[3]

Published online: 27 November 2017
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Remote sensing can be defined as the process of measuring the physical properties of distant objects using reflected or emitted energy [1]. Remote Sensing (RS) refers to the science of identification of earth surface features and estimation of their geo-biophysical properties using electromagnetic radiation as a medium of interaction. Spectral, spatial, temporal and polarization signatures are major characteristics of the sensor/target, which facilitate target discrimination. Earth surface data as seen by the sensors in different wavelengths (reflected, scattered and/or emitted) is radiometrically and geometrically corrected before extraction of spectral information [2, 3]. Remote Sensing data, with its ability for a synoptic view, repetitive coverage with calibrated sensors to detect changes, observations at different resolutions, provides a better alternative for natural resources management as compared to traditional methods [4, 5].

Remote sensing of earth has come a long way from nineteenth century aerial photography [6] to latest UAV remote sensing. In general sense, remote sensing at present means satellite remote sensing and it started with the launch of Landsat-1 in 1972 for civilian applications [7]. In 1979, Seasat-1 became the first RADAR imaging satellite [8] and started a new domain of remote sensing. Over the following years, the field of satellite remote sensing has seen many exciting new developments such as new higher spatial resolution optical and radar systems, hyperspectral sensors, important by-products such as digital elevation model (DEM), furthermore development of new processing techniques using machine learning [9]. At present, Satellite series like Sentinel and Planet Labs are revolutionizing the sector by providing high spatial, spectral and temporal resolution data either free or at very low cost.

The integration of different types of remote sensing data, along with ancillary data from different sources, is driving many new scientific investigations ranging from estimating forest biomass to mapping of Mars surface for finding minerals [10–12]. Remote sensing data is also helping to develop a better geographical information system (GIS) which in turn can be used for education, land management, natural resources management, environmental and aeronautical applications. Government organisations are also opening their own portal to provide data to common citizen. Some of the major operational application themes, in which India has extensively used remote sensing data are agriculture, forestry, biodiversity, ground water targeting, water resources, land use, urban sprawl, geology, environment, coastal zone, marine resources, snow and glacier, disaster monitoring and mitigation, infrastructure development [13].

India's space program began in 1960's under the guidance of Dr Vikram Sarabhai. With the launch of IRS-1A in 1988, India started its own remote sensing program. Till date, India has successfully launched tens of satellites including high spatial resolution Cartosat satellites and radar imaging RISAT satellites. In that process, Polar Satellite Launch Vehicle (PSLV) became one of the most

✉ P. S. Roy
psroy13@gmail.com

M. D. Behera
mdbehera@coral.iitkgp.ernet.in

S. K. Srivastav
sksrivastav@iirs.gov.in

1 University of Hyderabad, Hyderabad, India

2 Indian Institute of Kharagpur, Kharagpur, India

3 Indian Institute of Remote Sensing, Dehradun, India

successful satellite delivery system. Apart from serving India's needs, the Indian remote sensing satellites also serve the requirements of its south Asian neighbours. Besides remotely sensing the earth surface, India has also successfully planned and executed a Moon mission (Chandrayaan) and a Mars mission (Mangalyaan) on the first attempt [14–16]. India has also made considerable progress in human resource development in space technology and applications [17].

The **first three review papers** from three leading Institutions of Indian Space Research Organisation (ISRO) highlight on the diversity and developments in remote sensing (1) sensor systems, (2) applications aimed at societal development and national building, and (3) data processing and analysis using soft computing techniques. **Misra (2017)** has reviewed the Indian remote sensing sensor system with respect to current and future prospects, where he argues that India has the world's largest constellation of remote sensing satellites in operation which is being extensively used for resource management and integrated planning for national development. He mentioned on the series of earth observation systems in both polar and geo-synchronous orbits starting from Bhaskara, the first experimental Earth Observation satellite in 1979 to Cartosat-2E successfully launched in 2017. He has reviewed the active and passive sensors in both optical and microwave spectral regions, providing valuable data at different spatial resolutions for land, ocean and atmospheric applications for protecting the global environment, reducing disaster losses, and achieving sustainable development. **Krishnamurthy and Rao (2017)** have discussed on the Remote sensing applications ranging from the mapping of natural resources using hard copy aerial colour and infrared photographs in 1970s to bio-geophysical parameters retrieval and providing solutions by integrating space technologies inputs from satellite remote sensing, navigation systems and mobile services through satellite communication. They analysed that Remote sensing has been playing major roles in societal applications by maximizing outreach of natural resources information to the Central and State governments, industry and voluntary agencies. They are of the opinion that improved availability of satellite data and affordability of computational infrastructure would further enhance utilization of remote sensing technology in sustainable development and capacity building aimed towards societal needs. **Kumar et al. (2017)** have advocated that the soft computing methods outperform conventional methods when they are applied to complex data handling, especially for multi-source and very high dimensional data classification with one or more combination of classifiers. They are of the view that soft computing techniques such as deep learning, analytical hierarchical processes and feature extraction from hyperspectral imagery and applications of optimization techniques like particle swarm optimization, genetic algorithms in handling remote sensing problems have been covered to encourage research community for further exploration.

The **next ten review papers** from leading remote sensing practitioners from academic and R&D Institutions in India, extensively discussed on various remote sensing platforms and applications domains viz., (1) Semantics and High-Performance Computing Driven Approaches for Earth Observation (EO) Data, (2) Hyperspectral Data Processing and Analysis Algorithms, (3) Design and development of higher order spectral unmixing models for accurate abundance estimation of mixed pixels, (4) Airborne LiDAR Technology: data collection and processing Systems, (5) SARAL/AltiKa Mission: New and challenging applications with Ka-band altimetry, (6) Cryospheric Studies in Indian Himalayan and Polar Region, (7) Sustainable Biodiversity Management using Remote sensing in India, (8) Satellite Remote Sensing for Ocean Biology, (9) Hydrological Parameters Estimation using Remote Sensing and GIS for Indian Region, (10) Satellite radar altimetry for inland hydrology studies focusing on SARAL/AltiKa applications in Indian inland waters.

Surya et al. (2017) reviews earth observation Image information mining from semantics based approaches. The need for mining of RS data has arisen due to the ever-increasing amount of data that is being collected by various Earth Observation (EO) platforms. The EO data archives are reaching to unmanageable sizes, and the challenges in storing and disseminating this information is reaching alarming proportions. It is believed that 90% of this data remains in the archives, untouched. Currently, the data is made available to the user through interfaces that support only syntactical queries, and lack the intuitiveness which does not cater to the user's conjecture. These limiting factors highly affect the usage of these archived datasets. This review which is based on selected papers covers three areas of Earth Observations, which can benefit from the integration of semantic technologies: (1) Data from EO Imagery (2) EO data in the form of Thematic data. The recent advent of Graphical Processing Units (GPU's) for general purpose computing has tremendously helped in developing rapid approaches for mining EO image archives. The various processes involved in using the GPU computing in various EO applications are discussed along with the recent work in this domain.

Kale et al. (2017) have discussed on the recent advances in the sensors technology for imaging spectroscopy coupled with high computing power that raise the demand to develop the algorithms for processing and analysis of hyperspectral data for various applications. They have discussed on the techniques for atmospheric correction, dimensionality reduction, end-member extraction and classification; and critically reviewed hyperspectral data processing and analysis approaches and argued for the development of robust algorithms for hyperspectral data processing and analysis. **Chakravortty and Chakrabarti** (2017) evaluated the potential of Hyperspectral imagery acquired by the Hyperion Sensor for improved species level discrimination of pure and mixed mangrove patches growing in natural habitats. While linear interactions are usually taken care of by extant linear spectral unmixing models, it was difficult to compute the intricate cobweb of non-linear interactions resulting out of pure and mixed pixels. The closed-patch mangrove forest of Sunderbans is particularly characterized by mixed stands (pixels) that bear several mangrove species (endmembers) embedded in a closed system. In order to fully characterize these non-linear interactions, a new 'Higher Order Non-Linear Spectral Unmixing Model' was developed that helps to overcome the limitations of the prevalent linear spectral unmixing models and takes care of single interactions.

Lohani and Ghosh (2017) discoursed on various types of airborne LiDAR (Light Detection and Ranging) sensors on their working, data format and data quality assessment procedures and the data analysis techniques including new approaches like CNN (Convolutional Neural Networks) and visual analytics for data processing. They have outlined the future scope of the technology and the research challenges and advocated that it has now become industry standard tool for collecting accurate and dense topographic data at very high speed.

Observations from AltiKa (nadir altimeter in Ka-band) onboard the *Satellite with ARGOS and AltiKa* (SARAL) are useful in coastal altimetry, inland hydrology and cryosphere (continental and sea ice) applications **(Kumar et al. 2017)**. High rate (40-Hz) data from AltiKa has been exploited for retrieving very useful oceanic parameters (sea surface height anomaly, significant wave height and ocean surface wind) in the coastal waters (up to $\sim$ 3 km from the coast) of Indian landmass region. They informed that East Antarctica is gaining ice with maximum change of 0.6 m in many regions, with Thwaites and Pine Island glacier $>$ 2 m reduction in the elevation. **Ghosh et al. (2017)** have reviewed the satellite radar altimetry data processing technique, analysis, and interpretation with special focus on Indian inland waters using SARAL/AltiKa data. They have elaborated on the basic working principle of altimetry, altimetry waveform, and waveform retracking methods, water stage/discharge calculation procedure and the status of altimetry applications to inland hydrology, specifically solicitation of SARAL/AltiKa in Indian context.

Thakur et al. (2017) focused on remote sensing based methods of mapping snow and glaciers including aerial, space based satellites and unmanned aerial vehicles (UAV) based platforms. They have also discussed some of the historical terrestrial photogrammetric methods used for glaciers studies in India by Survey of India (SOI). **Thakur et al. (2017)** contended that satellite based remote sensing has proven its usage in effective mapping/retrieval and monitoring of hydrological parameters such as precipitation, interception, soil moisture, surface runoff, surface water storage, surface water quality, evapotranspiration, change in terrestrial water storage, water level and river flow, etc. The basics of retrieval techniques, applications, modelling, validation and limitations are discussed along with the progress of each technique from optical to microwave remote sensing.

Reddy et al. (2017) presented consolidated information of earth observation based biodiversity research and conservation applications in India with reference to species populations, species traits, community composition, ecosystem function and ecosystem structure in the context of essential biodiversity variables. They have discussed on the remote sensing based biodiversity indicators in understanding of land cover, forest cover, forest type, fragmentation, biological richness, carbon stocks, fires and protected area monitoring at multiple spatial and temporal scales. **Chauhan and Raman (2017)** have reviewed the works done in India during the last three decades in the broad field of space based marine biology. They opine that space based observations using ocean colour sensors including OCM-1 and OCM-2 have provided unique information about the global distribution and temporal variability of oceanic phytoplankton.

The **twenty-two papers on remote sensing research and applications** from leading remote sensing practitioners from academic and R&D Institutions in India and abroad cover most of the domains with satellite imageries of varied resolution, various data processing analysis and modelling techniques showcasing the strength and potential of remote sensing and the kindred technologies for the benefit of human being. **Kumar et al. (2017)** have demonstrated a novel multi-sensor approach combining multispectral and Radar data to model mangrove biophysical characteristics in Coastal Odisha, India. The long-term analysis revealed phenological patterns in the biophysical characteristics such as high values during wet season and low values during the dry season. Correlations between biophysical characteristics and meteorological factors revealed that a time lag exists in response to precipitation and associated runoff. This research can be a valuable resource for future monitoring and management of mangrove ecosystem and their carbon sequestration abilities in coastal India.

Karnatak et al. (2017) have developed and implemented a WPS based geo-processing and analysis approach using Online Image Processing System (OIPS). The software framework offers a platform independent solution that was developed using free and open source technology. They have demonstrated a case study through Normalized Difference Vegetation Index (NDVI) and Normalized Difference Built-up Index (NDBI) annotated algorithms for automatic deployment in geo-scientific processing workflow environment. The proposed approach can be very effective and useful to address the key challenges in commercial desktop based software for geo-processing and analysis of remote sensing data, they claim.

Handique et al. (2017) presented the results and observations made from pilot exercises on crop discrimination using *Parraot Sequoia* multispectral sensor onboard UAV. They have successfully attempted to discriminate four horticultural crops viz. banana, orange, and plum and the neighbouring bamboo grooves were evaluated using three commonly used indices viz., Normalized Difference Vegetation Index (NDVI), Normalized Difference Red Edge Index (NDRE) and Green Normalized Difference Vegetation Index (GNDVI); and variation in Digital Surface Model (DSM) and Digital Terrain Model (DTM).

Mukherjee et al. (2017) have developed an algorithm for calibrating DMSP/OLS data for socio-economic monitoring. The study formulates an algorithm to automatically extract regions with stable luminosity throughout time, called as Pseudo Invariant Features (PIFs), without any need of prerequisite knowledge of the study area.

Bhavani et al. (2017) applied an approach to integrate various datasets i.e., satellite and climate variables including socio-economic to assess the agricultural drought vulnerability at the district level, and Tehsil level of united Telangana and Andhra Pradesh states for the recent-past. The study revealed that climate and soil moisture have a significant impact on LGP and agriculture condition; and thereby has implications to plan appropriate adaptive and mitigation strategies for the agricultural drought conditions in changing climate scenario.

Sarif et al. (2017) have attempted to quantify the spatio-temporal dynamics in forest cover in Jharkhand state since its formation (i.e., year 2000) with the help of time-series tree cover information. Moderate Resolution Imaging Spectroradiometer (MODIS) based Vegetation Continuous Fields (VCF) data revealed negative changes in the Latehar, Lohardaga and West Singhbhum districts, and positive changes over other forested regions of the state during 2000 to 2014.

Ghosh et al. (2017) developed a methodology for crop and crop fallow land estimation using multi-temporal, high spatial resolution Sentinel-2A data in a test site of Odisha state, India. Observing the variation of NDVI over time, they attempted to estimate crop life cycle duration and their type with rigorous field inputs. There is scope to utilise the fallow lands for multi-cropping with appropriate land and water management, through the government policy prescriptions, this study opines.

Shaji et al. (2017) studied seasonal variability of SST and air-sea fluxes and quantified their relations using satellite-sensed Sea Surface Temperature (SST), winds, and air-sea fluxes in the Lakshadweep Sea (LS). They found that warming during the month of May is the resultant of the expansion of Indian Ocean warm pool into the LS and westward propagation of the Lakshadweep High (LH) as downwelling Rossby wave; and for warming during November, vertical ocean heat convergence and less evaporation act favourably.

Jayaram et al. (2017) have generated Global 2-day mean wind fields of Oceansat-2 scatterometer (OSCAT) using variational data analysis method, and validated using in situ observations from buoys and Advanced Scatterometer (ASCAT) for different global ocean basins and wind speed ranges at 0.5° grids. They suggested that the resultant OSCAT gridded winds can be used to generate value added products like wind stress and curl for the global oceans.

Shashi Kumar et al. (2017) have tested the potential of multi-baseline SAR tomography data with 6 scenes of SAR data for forest height retrieval over Dudhwa National Park, India. Vertical profile generated from capon algorithm had shown different forest height values at different locations in range direction for single azimuth bin. Tomography based forest height was compared with field-measured forest height for 190 locations that led them to conclude that forest height with reliable accuracy can be retrieved with space-borne PolInSAR tomography.

Shashi Kumar et al. (2017) have evaluated the performance of bistatic X-band PolInSAR pair for forest height retrieval by implementing two algorithms i.e., three stage inversion (TSI) and coherence amplitude inversion (CAI) on the complex coherences obtained from PolInSAR processing. Both the inversion algorithms showed their potential for forest height retrieval through bistatic PolInSAR data. This study found that space-borne bistatic SAR has great potential to preserve coherence values for forest height estimation in tropics.

Kale et al. (2017) have addressed the forest fires in India and its connection with different climate drivers, fuel status and anthropogenic disturbances. The forest fire is significantly (significance $f < 0.05$, confidence interval 95%) correlated with average dry-days (r 0.75) and maximum average temperature (r 0.76). They further observed that El Niño increased the temperature and consequently the dryness, which created conducive conditions for fire to occur. Their analysis revealed that the fire occurrence in Deccan Peninsula and the central Himalaya in particular are more sensitive towards the climate anomalies.

Swain et al. (2017) analysed the effect of Urban Heat Island UHI on Bhubaneswar City, India, utilizing Land Use and Land Cover (LULC) change and Land Surface Temperatures (LST) for past 15 years. They suggest that analyses of the changes in the urban energy balance and resulting UHI effect across many such Indian cities undergoing rapid urban growth is essential for mitigating the impacts of urbanization for long-term sustainability.

Mann and Joshi (2017) have tested the effect of improved spectral and spatial resolution on classification performance of ASTER data (15 m), Hyperion data (30 m) and their fused product (15 m). Using five supervised classification algorithms—three spatial classifiers, namely, Maximum Likelihood (MLC), Support Vector Machines (SVM), Artificial Neural Network (ANN) and two spectral classifiers, namely, Spectral Angle Mapper (SAM) and Spectral Information Divergence (SID), they observed that MLC and SVM performed the best.

Nagamani et al. (2017) studied to monitor and identify the phytoplankton blooms using Oceansat-2 Ocean Colour Monitor (OCM-2) data all along the East coast of India. Using in situ biological measurements and optical detection using spectral discrimination, they observed a unique peak at 483 nm, attributed to *Skeletonema Coastatum* species which is identified from the chlorophyll product derived from OCM-2. They suggested that diatom blooms can be detected from OCM-2 data using characteristic peaks.

Bandyopadhyay et al. (2017) used hyperspectral image from Hyperion sensor to indicate the strand growth and vigor of *Shorea robusta* (Sal) forest by estimating foliar nitrogen in Doon Valley. This study implies that Spatial N distribution map has potential to be used in predicting carbon sequestration potential and disturbances caused due to pest-insect infestation, anthropogenic pressure and site degradation.

Mohit Kumar et al. (2017) assessed the ecological changes in mangroves and coral reefs of Marine National Park and Sanctuary (MNP&S), Gulf of Kachchh, Gujarat, India during 1972 to 2014 using Landsat data. The analysis showed that MNP&S witnessed severe loss of mangroves till 1992, with annual rate of mangrove degradation being 2.89% that could be reasoned to (1) mining and deposition of sediments, (2) exploitation by local communities and (3) careless release/spillage of oil and brine by nearby industries.

Issac et al. (2017) studied field level irrigation water requirement from soil water stress coefficient (Ks) derived from water balance components (WBCs), estimated from a process based hydrological model (Variable Infiltration Capacity Model: VIC-3L) in Kurnool Cuddapah Command (KCC) area. This methodology helped in identifying intermittent wet & dry periods requiring irrigation intervention; and thereby provides opportunities to estimate realistic irrigation requirement.

Matin et al. (2017) studied the congruence between plant and animal biological richness (BR) by extending the scope of methodology from past studies in order to understand the question; does higher plant richness encourages higher animal richness? The strengths of their study are (1) translation of animal characterization onto a spatial map, (2) collection and utilization of scattered data of animals from varied resources for Indian region where proper documentation is lacking, (3) generation of an inclusive BR map having higher conservation potential, and (4) creation of a database having retrieval and future modification capability. This methodology has the potential for inclusive plant and animal biological richness for effective conservation implications with more site-specific data of a wider range of animals, they claim.

Mahanand and Behera (2017) analysed the distribution of plant species richness with respect to the Moderate Resolution Imaging Spectroradiometer (MODIS) derived biophysical proxies, i.e., Normalized Difference Vegetation Index (NDVI), Enhanced Vegetation Index (EVI), Fraction of absorbed Photosynthetically Active Radiation (*f*PAR), Leaf Area Index (LAI), and surface reflectance (SR-645 nm and SR-858 nm) and found weak positive correlation. They argue that utility of fine resolution spatio-temporal data on species richness relationship with biophysical proxies can be better explained, and thereby help in long-term biodiversity monitoring.

Amarnath et al. (2017) have demonstrated the utility of less data intensive, but equally robust hydrodynamic models to develop flood extent maps in conjunction with freely available remote sensing imageries at different scales. They claim that their proposed approach is suited for mapping flood extents to provide input information in near real time (hours) when there is no availability to detailed hydraulic models and satellite datasets.

Saji and Jayakumar (2017) have identified areas under actual and potential desertification risk by modelling four indicator thematic layers (soil, climate, vegetation and anthropogenic pressure buffers) in GIS environment using three Representative Concentration Pathways (RCPs). They observed that the areas experiencing various risk states belong to the foothills and mid slopes of the forest region and fall within the semiarid to dry sub-humid aridity zones.

Appendix

http://www.isro.gov.in/pslv-c25-mars-orbiter-mission (Accessed on 15th September 2017).

http://www.isro.gov.in/pslv-c11-chandrayaan-1 (Accessed on 15th September 2017).

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